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INVESTIGATION OF PERFORMANCE OF CONCRETE AND CONCRETING MATERIA--ETC(U)

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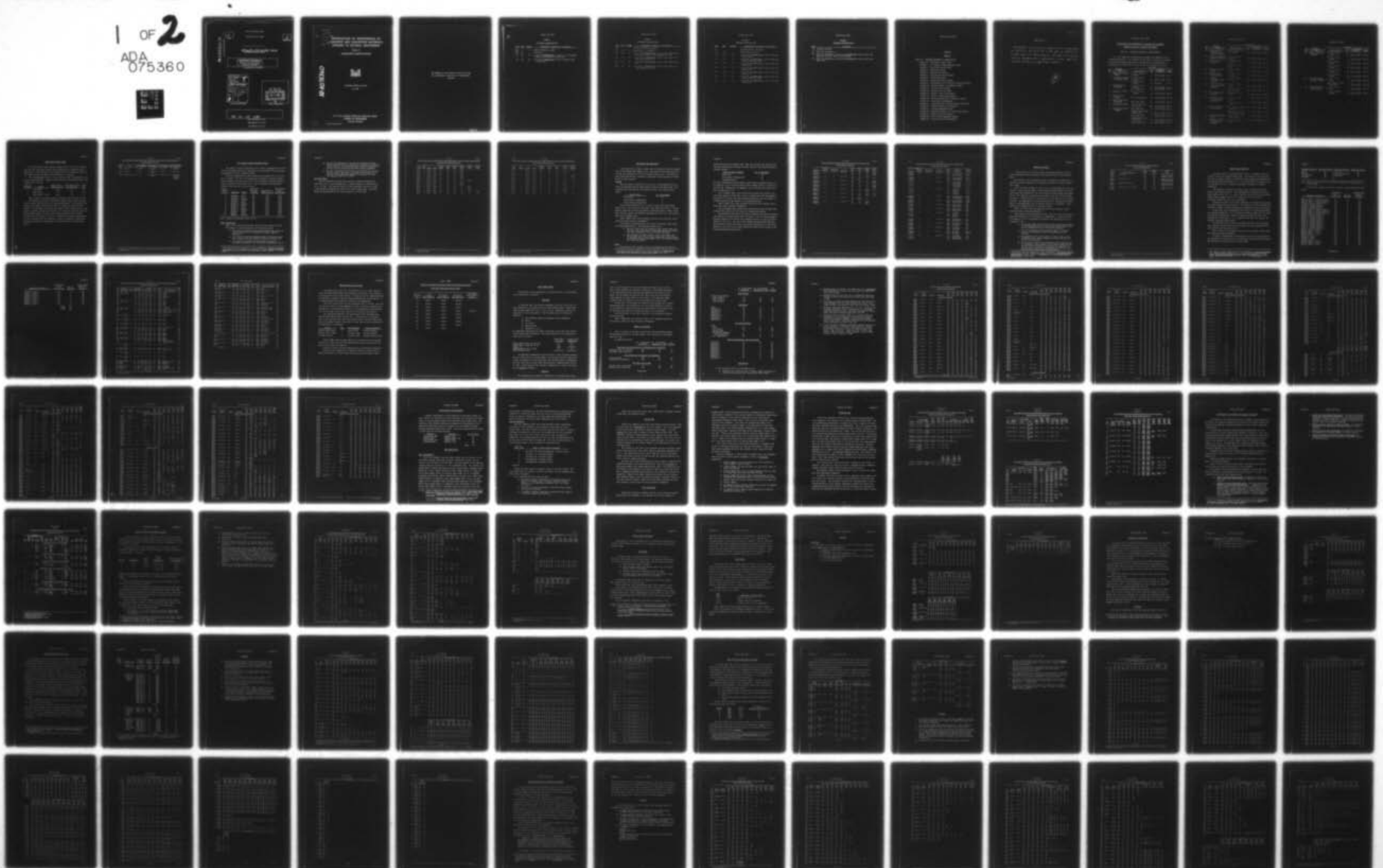

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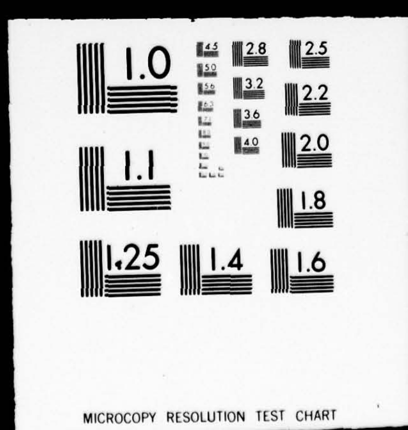

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INVESTIGATION OF PERFORMANCE OF CONCRETE AND CONCRETING MATERIALS EXPOSED TO NATURAL WEATHERING

Volume 2

COMPLETED INVESTIGATIONS

TECHNICAL REPORT NO. 6-553

June 1961

U. S. Army Engineer Waterways Experiment Station

CORPS OF ENGINEERS

Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS.

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(Issued Jan 1973)

VOLUME 2

COMPLETED INVESTIGATIONS

Item	Part	Program	Supplement, Correction, or Revision
✓33	--	--	Revised Contents (1 page)
✓34	III	--	Revised p 3
35	III	22	A new item ~~including Key~~ (1 page); text (2 pages); Tables 1-PF and 2-PF (1 page each)
36	III	23	A new item ~~including Key~~, text, and Table 1-GLD (1 page each)

(Issued Sept 1968)

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COMPLETED INVESTIGATIONS

Item	Part	Program	Supplement, Correction, or Revision
33			Revised Contents (one page)
34	III	--	Reprinted p 1; revised p 2
35	III	17	A new item (~~including key;~~ 3 pp of text; Table 1-PCA, 2 pp; Table 2-PCA, 2 pp; Appendix A, 4 pp)
36	III	18	A new item (~~including key~~; 3 pp of text; Table 1-VP, 2 pp; Table 2-VP, 1 p)
37	III	19	A new item (~~including key~~; 2 pp of text; Table 1-PK, 1 p)
38	III	20	A new item (~~including key~~; 3 pp of text; Table 1-Z, 2 pp; Appendix A, 8 pp)

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42			Revised Contents (one page)
43	III	--	Reprinted p 1; new p 2
44	III	10	A new item (including key; 2 pp of text; and Table 1-NBS)
45	III	11	A new item (including key; 3 pp of text; and Tables 1-ADB and 2-ADB)
46	III	12	A new item (including key; 2 pp of text; and Table 1-SY)
47	III	13	A new item (including key; 3 pp of text; and Table 1-CRN)
48	III	14	A new item (including key; 4 pp of text; and Table 1-VR)
49	III	15	A new item (including key; 2 pp of text; and Tables 1-FLC and 2-FLC)
50	III	16	A new item (including key; 1 pp of text; and Table 1-FL)

(Issued Aug 1963)

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Item	Inclosure
42	Contents, revised
43	Part III, revised p 1
44	Part III, Program 8, a new item (~~including Key;~~ 5 pp of text; and Tables 1-CJ; 2-CJ, 3-CJ (1 p); and 4-CJ)
45	Part III, Program 9, a new item (~~including Key~~, 2 pp of text, and Table 1-F)

(Revised Jan 1973)

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ABSTRACT

Completed investigational programs are summarized in tabulation. The remainder of the report is devoted to a discussion of these programs and specific findings of each together with a presentation of the exposure records of the test specimens involved.

(Reprinted Sept 1968)

INVESTIGATION OF PERFORMANCE OF CONCRETE AND CONCRETING MATERIALS EXPOSED TO NATURAL WEATHERING

PART III: COMPLETED PROGRAMS OF INVESTIGATION

15. The completed investigational programs are summarized in the following tabulation. The remainder of this part is devoted to a discussion of these programs and specific findings of each together with a presentation of the exposure records of the test specimens involved:

Program		Specimens			
			Installed		
No.	Title	Size and Kind	No.	Location	Date
1	High-Alkali Cement Study	6- × 6- × 48-in. columns	3	Treat Island	Oct 41
2	St. Lawrence Seaway Aggregate Study	6- × 6- × 48-in. columns	12	Treat Island	Oct 41
		6- × 6- × 48-in. columns	12	New York	Oct 41
3	John Martin Dam Specimens	6- × 6- × 30-in. columns	24	Treat Island	Oct 41
		8-in.-diam cores	42	Treat Island	Oct 41
4	Admixture N Study	6- × 6- × 48-in. columns	12	Treat Island	Mar 42
5	Stewart Field Spheres	12-in.-diam spheres	93	Treat Island	Oct 43
6	Upper Narrows Dam Specimens	6-in.-diam cores	18	Treat Island	Jan 44
7	Curing Media Study	3-1/2 × 4-1/2 × 20-in. prisms	300	Treat Island	Feb 43
8	Construction Joint Program	8-in.-diam cores	9	Treat Island	Oct 41
		Insulated 8-in.-diam joint cores	10	Treat Island	Oct 42
		8-in.-diam cores	4	Treat Island	Mar 43
		Insulated 8-1/4-in.-diam cores	23	Treat Island	Dec 43
		12-in.-diam cores	40	Treat Island	Dec 43

(Revised Sept 1968)

Program No.	Program Title	Specimens: Size and Kind	Installed No.	Installed Location	Installed Date
9	Investigation of Finishes for Concrete Surfaces	3-1/2 × 16-1/2- × 30-in. panels	17	Treat Island	June 59
10	National Bureau of Standards Program	6- × 6- × 48-in. columns	116	Treat Island	Oct 43
11	Rome Air Depot Program	6- × 6- × 48-in. beams	15	Treat Island	Dec 41
		5-1/2- × 6- × 30- beams	3	Treat Island	Oct 43
12	Syracuse Air Base Beams	6- × 6- × 48-in. beams	18	Treat Island	Oct 42
13	Natural Cement Investigation	6- × 6- × 48-in. columns	94	Treat Island	Oct 42
14	Resin Air-Entraining Agent Program	6- × 6- × 48-in. columns	182	Treat Island	Oct 43
15	Field and Laboratory Correlation Program	6- × 6- × 30-in. beams	150	Treat Island	Dec 48
		3-1/2- × 4-1/2- × 16-in. beams	150	Treat Island	Dec 48
16	Form Lining Investigation	6-in. diam × 8-in. cores	68	Treat Island	June 46
17	Long-Time Study, Portland Cement Association	6- × 6- × 30-in. beams	66	Treat Island	Oct 41
		6- × 6- × 30-in. beams	58	Treat Island	May 54
18	Vacuum Treatment Investigation	8-in. diam × 9-1/2-in. long cores	10	Treat Island	Oct 49
		10-in. diam × (16- or 18-in.) long cores	36	Treat Island	Oct 49
19	Preplaced Aggregate Cores	10-in. diam × 16-in. long cores	9	Treat Island	Oct 49
20	Cooperative Study of Air-Entrained Concrete	3- × 4- × 16-in. beams	48	Treat Island	Nov 51

(Revised Jan 1973)

Program No.	Program Title	Specimens Size and Kind	Installed No.	Installed Location	Installed Date
21	Cement Durability Program	6- × 6- × 48-in. columns	271	Treat Island	Oct 40
		6- × 6- × 48-in. columns	5	Treat Island	Jan 41
		6- × 6- × 48-in. columns	12	Treat Island	June 41
		6- × 6- × 48-in. columns	25	Treat Island	Oct 41
		6- × 6- × 48-in. columns	48	Treat Island	Oct 42
		6- × 6- × 48-in. columns	152	St. Augustine	Nov 40
22	Pine Flat Dam Aggregate Program	2- × 2- × 2-ft cubes	6	Treat Island	Sept 47
		10-in. diam × 18-in. long cores	3	Treat Island	Fall 49
23	Greenup Lock and Dam Specimens	2- × 2- × 2-ft cubes	4	Treat Island	Oct 57
		6- × 6- × 30-in. columns	10	Treat Island	Oct 57

High-Alkali Cement Study

In October 1941, three concrete columns (6 by 6 by 48 in.), containing high- and low-alkali cements, were installed on the exposure rack at Treat Island. The purpose of this installation was to study the effect of high-alkali content in cement on the durability of concrete.

The sand-aggregate ratio of the concrete was 34%; the aggregates were natural sand and gravel. Cements, cement factors, water-cement ratios, and slumps were as follows:

No. of Specimens	Cement	Cement Factor bags per cu yd	Water-Cement Ratio gal per bag	Slump in.
1	Low alkali	5.25	6.0	5.5
1	High alkali	5.25	6.0	5.0
1	High alkali + resin	5.32	5.5	5.0

Table 1-HACP lists these specimens and gives their exposure record.

The specimen containing a high-alkali cement without resin was definitely unsound after 294 cycles of freezing-and-thawing. The specimen containing a low-alkali cement failed after two winters of exposure (353 cycles). The specimen containing a high-alkali cement treated with a resin showed a relative modulus of elasticity of 109 per cent after 353 cycles of freezing-and-thawing. However, this specimen suffered severe surface scaling after two winters on the rack. Despite this surface deterioration, it can be inferred that the influence of resin in causing air entrainment materially increased the durability of concrete made with a high-alkali cement.

Table 1-HACP

Program I

Record of Testing of Concrete Columns for Effect of High-Alkali Content in Cement on Durability, Treat Island

1941-1943 (Installed October 1941)

Specimen No.	Cement	0 Cycles, Oct 1941		37 Cycles, Dec 1941		155 Cycles, Mar 1942		353 Cycles, Apr 1943	
		%E	Condition	%E	Condition	%E	Condition	%E	Condition
DVE-14	Low alkali	---	Broken*	---	Slight deterioration	---	Raveling	F**	Disintegrated
DVE-37	High alkali	100	Sound	107	Slight deterioration	57	Raveling	F	Disintegrated
DVE-60	High alkali plus resin	100	Sound	108	Slight deterioration	113	Slight spall	109	Severe surface scaling - exposure discontinued in Aug 1943

* This specimen was broken at installation; both (2) segments were installed. Therefore sonic readings were not taken.

** F denotes failed.

St. Lawrence Seaway Aggregate Study*

The purpose of this investigation was to find an aggregate that would give the greatest assurance of durability of the concrete for the proposed construction of the St. Lawrence Seaway.

Concrete representing 12 test conditions was molded into 6- by 6- by 48-in. columns. One set of 12 columns was installed on the Treat Island rack in October 1941; the other set of 12 was exposed to moderate weathering out-of-doors at West Point, N. Y. The 12 conditions and characteristics of the concrete are given below:

Test Condition No.	Aggregate	Cement	Absorptive Form Lining Used	Cement Factor bags per cu yd	Water-Cement Ratio gal per bag
1	Dolomite	Plain	No	5.50	6.00
2	Dolomite	Plain	Yes	5.50	6.00
3	Dolomite	Treated	No	5.50	5.75
4	Gravel G	Plain	No	4.75	6.00
5	Gravel G	Plain	Yes	4.75	6.00
6	Gravel G	Treated	No	4.75	5.60
7	Gravel P	Plain	No	4.75	6.00
8	Gravel P	Plain	Yes	4.75	6.00
9	Gravel P	Treated	No	4.75	5.60
10	Syenite	Plain	No	5.75	6.00
11	Syenite	Plain	Yes	5.75	6.00
12	Syenite	Treated	No	5.75	5.75

Note: Slump of all mixtures was 2-1/2 in.

Treat Island group

Table 1-STL lists these specimens and gives their exposure record.

The exposure at Treat Island gave the following results:

a. The concrete containing resin-treated cement and syenite aggregate (condition 12) possessed the highest degree of durability.

b. The concrete containing untreated cement and syenite aggregate possessed the next highest durability (condition 11).

c. The concrete containing untreated cement and gravel P possessed exceptionally poor durability (conditions 7 and 8).

* See Central Concrete Laboratory, Corps of Engineers, Report of Concrete Investigations - St. Lawrence River Waterway - Series CR-STL (30 January 1942).

<u>d</u>. The lack of durability in the concrete containing unsound gravel indicates that the presence of entrained air resulting from the use of a resin-treated cement cannot be expected to protect concrete containing definitely unsound aggregate.

<u>e</u>. The use of absorptive form lining was ineffective in protecting the inferior aggregate, but improved the durability of concrete containing sound aggregate as compared with that cast against forms not so lined.

<u>New York group</u>

The 12 specimens which had been exposed to moderate weathering at West Point, N. Y., were transferred to a similar exposure at Mount Vernon, N. Y., in 1942. The exposure record of these specimens is given in table 2-STL and may be compared with that of the Treat Island group. The specimens were discarded after the final inspection in April 1946.

Table 1-STL

Program 2

Record of Testing of Concrete Columns Containing Various Aggregates Proposed for Use in St. Lawrence Seaway Construction

Treat Island, 1941-43 (Installed October 1941)

Specimen No.	Test Condition	Aggregate	Cement	Absorptive Form Lining Used	0 Cycles Oct 1941 %E	37 Cycles Dec 1941 %E	95 Cycles Jan 1942 %E	166 Cycles Apr 1942 %E	353 Cycles Apr 1943 %E
STL-PC	7	Gravel P	Plain	No	100	100	Failed		
STL-PB	8	Gravel P	Plain	Yes	100	106	Failed		
STL-PBV	9	Gravel P	Treated	No	100	101	Failed		
STL-NC	1	Dolomite	Plain	No	100	134	Failed		
STL-NE	2	Dolomite	Plain	Yes	100	104	Failed		
STL-NBV	3	Dolomite	Treated	No	100	146	117	Failed	
STL-GC	4	Gravel G	Plain	No	100	98	Failed		
STL-GB	5	Gravel G	Plain	Yes	100	99	Failed		
STL-GBV	6	Gravel G	Treated	No	100	106	53	Failed	
STL-LC	10	Syenite	Plain	No	100	104	105	Failed	
STL-LB	11	Syenite	Plain	Yes	100	103	108	103	Failed
STL-LCV	12	Syenite	Treated	No	100	108	110	115	113*

* Exposure discontinued.

Program 2

Table 2-STL

Record of Testing of Concrete Columns Containing Various Aggregates Proposed for Use in St. Lawrence Seaway Construction

New York, 1941-46 (Installed October 1941)

Specimen No.	Test Condition	Aggregate	Cement	Absorptive Form Lining Used	0 Cycles 1941 %E	68 Cycles 1942 %E	330 Cycles 1944 %E	600 Cycles 1946 %E (Final)
STL-PD	7	Gravel P	Plain	No	100	103	107	118
STL-PE	8	Gravel P	Plain	Yes	100	104	Failed	
STL-PCV	9	Gravel P	Treated	No	100	106	111	133
STL-NB	1	Dolomite	Plain	No	100	108	112	Failed
STL-NE	2	Dolomite	Plain	Yes	100	106	109	66
STL-NCV	3	Dolomite	Treated	No	100	108	111	111
STL-GC	4	Gravel G	Plain	No	100	107	Failed	
STL-GD	5	Gravel G	Plain	Yes	100	114	Failed	
STL-GCV	6	Gravel G	Treated	No	100	111	119	126
STL-LD	10	Syenite	Plain	No	100	103	Failed	
STL-LE	11	Syenite	Plain	Yes	100	102	Failed	
STL-LBV	12	Syenite	Treated	No	100	102	114	86

Note: Exposure discontinued in 1946.

John Martin Dam Specimens*

In October 1941, concrete columns cast from mixtures used in construction of John Martin Dam, Caddoa, Colo., and concrete cores extracted from the dam were installed on the Treat Island exposure rack. The purpose of these installations was to study the influence of form lining on the durability of mass concrete.

Columns

The 24 concrete columns (6 by 6 by 30 in.) were prepared from concrete wet-screened from the field mixtures used at John Martin Dam. The specimens were cast against three types of forms, one unlined and two lined.

Type of Form	No. of Specimens
Oiled wood	12
Form lining A (absorptive)	9
Form lining B (absorptive)	3

Three cement factors (3.0, 3.5, and 4.0) and three water-cement ratios (6.50, 7.18, and 7.61) were used. The cement was type II. The aggregate consisted of gravel principally containing granite, quartz, feldspar, diorite, basalt, and sandstone (maximum size 1-1/2 in.; wet-screened from a 6-in. maximum size).

Table 1-JMDP lists these specimens and gives their exposure record along with other pertinent information.

All specimens had failed after two winters of exposure (352 cycles of freezing-and-thawing). The indicated results were:

a. The use of the types of absorptive form lining tested will provide concrete surfaces of appreciably greater durability than that obtained by the use of oiled wood forms.

b. The influence of cement content in the lower ranges and water-cement ratio in the higher ranges upon the durability of absorptive form-lined surfaces was not as marked as might have been anticipated.

Cores

The forty-two 8-in.-diameter cores were diamond-drilled from the

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* See Central Concrete Laboratory, Corps of Engineers, Final Report, John Martin Dam, Durability of Cores and Columns (July 1942).

downstream face of John Martin Dam. They were drilled from concrete that had been cast against two types of forms, and also from concrete having a screeded surface:

Type of Form or Finish	No. of Specimens
Oiled wood	18
Form lining A (absorptive)	21
Screeded surface	3

The cores represented concrete having cement factors ranging from 3.0 to 4.0 bags per cu yd, and water-cement ratios ranging from 6.5 to about 9.0 gal per bag. Maximum size of aggregate in all concrete from which cores were extracted was 6 in.

On 11 December 1941, after having been exposed since October, the cores were placed in boxes (six in each of seven boxes) and surrounded by fine gravel to protect them from body disintegration, only the formed or finished surfaces being exposed to freezing-and-thawing.

Table 2-JMDP lists these specimens and gives their exposure record along with other pertinent information.

The wood-formed cores showed early deterioration which became severe in March 1942 after about 140 cycles of freezing-and-thawing.

The absorptive form-lined cores (form lining A) developed no significant evidence of deterioration after 164 cycles. None of these specimens appeared unsound in the center 5-in.-diameter area at the time of discontinuance of the test. The cores with screeded surfaces showed definite deterioration at about 140 cycles, and severe deterioration at 164 cycles. Therefore, the tests on the cores confirm the results of the tests on the column specimens described above.

Table 1-JMDP

Record of Testing of Columns Cast from John Martin Dam Concrete Against Three Types of Forms

1941-1943 (Installed October 1941)

Specimen No.	Water-Cement Ratio gal per bag	Cement Factor bags per cu yd	Type of Form	0 Cycles 1941 %E	164 Cycles 1942 %E	282 Cycles Feb 1943 %E	352 Cycles Aug 1943 %E
10M-738-W-1	7.61	3.0	Oiled wood	100	108	105	Failed
10M-738-W-2				100	87	85	Failed
10M-738-W-3				100	103	96	Failed
10M-738-L-1	7.61	3.0	Form lining A	100	83	Failed	
10M-738-L-2				100	103	100	Failed
10M-738-L-3				100	Failed		
32MF-745-W-1	6.50	4.0	Oiled wood	100	89	74	Failed
32MF-745-W-2				100	95	74	Failed
32MF-745-W-3				100	100	100	Failed
32MF-745-L-1	6.50	4.0	Form lining A	100	97	85	Failed
32MF-745-L-2				100	97	84	Failed
32MF-745-L-3				100	98	81	Failed
2BM-760-W-1	7.18	3.5	Oiled wood	100	95	95	Failed
2BM-760-W-2				100	91	Failed	
2BM-760-W-3				100	87	Failed	
2BM-760-L-1	7.18	3.5	Form lining A	100	100	74	Failed
2BM-760-L-2				112	112	Failed	
2BM-760-L-3				100	109	100	Failed
408-CF-2W-1	6.50	4.0	Oiled wood	100	Failed		
408-CF-2W-2				100	57	Failed	
408-CF-2W-3				100	Failed		
408-CF-2L-1	6.50	4.0	Form lining B	100	112	Failed	
408-CF-2L-2				100	103	Failed	
408-CF-2L-3				100	103	Failed	

Program 3

Table 2-JMDP

Record of Observations of Cores from John Martin Dam Concrete with Various Surface Finishes

1941-1942 (Installed October 1941)

Maximum size aggregate, 6 in.

Specimen No.	Water-Cement Ratio gal per bag	Cement Factor bags per cu yd	Type of Surface Finish	0 Cycles 1941 Condition	140 Cycles Mar 1942 Condition	164 Cycles Apr 1942 Condition
43-3780-TW	6.41	4.0	Oiled wood	Sound	Face disintegrated	Poor
43-3780-MW				Sound	Face disintegrated	Unsound
43-3780-LW				Sound	Face disintegrated	Very poor
43-3785-TW	7.11	3.8	Oiled wood	Sound	Face disintegrated	Very poor
43-3785-MW				Sound	Face disintegrated	Poor
43-3785-LW				Sound	Face disintegrated	Very poor
43-3790-TW	7.87	3.6	Oiled wood	Sound	Face scaling and edges raveling	Very poor
43-3790-MW				Sound	Face scaling and edges raveling	Very poor
43-3790-LW				Sound	Face scaling and edges raveling	Very poor
43-3795-TW	7.56	3.4	Oiled wood	Sound	Surface badly raveled	Unsound
43-3795-MW				Sound	Surface badly raveled	Unsound
43-3795-LW				Sound	Surface badly raveled	Very poor
43-3800-TW	8.05	3.2	Oiled wood	Sound	Face disintegrated	Unsound
43-3800-MW				Sound	Face disintegrated	Unsound
43-3800-LW				Sound	Face disintegrated	Unsound
43-3805-TW	9.18	3.0	Oiled wood	Sound	Face disintegrated	Unsound
43-3805-MW				Sound	Face disintegrated	Unsound
43-3805-LW				Sound	Face disintegrated	Unsound
43-3780-TL	6.41	4.0	Form lining A	Sound	Slight spalling	Sound
43-3780-ML				Sound	Moderate raveling	Sound
43-3780-LL				Sound	Minutely spalled	Sound
43-3785-TL	7.11	3.8	Form lining A	Sound	Slightly spalled	Sound
43-3785-ML				Sound	Slightly raveled	Sound
43-3785-LL				Sound	Moderately raveled	Sound
43-3790-TL	7.87	3.6	Form lining A	Sound	Some surface cracking	Sound
43-3790-ML				Sound	Raveling	Good
43-3790-LL				Sound	Face raveling badly	Good
43-3795-TL	7.56	3.4	Form lining A	Sound	Raveling badly	Fair
43-3795-ML				Sound	Moderately spalled	Sound
43-3795-LL				Sound	Some raveling	Good
43-3800-TL	8.05	3.2	Form lining A	Sound	Face raveled badly	Poor
43-3800-ML				Sound	Some raveling	Sound
43-3800-LL				Sound	Some raveling	Sound
43-3805-TL	9.18	3.0	Form lining A	Sound	Some raveling	Good
43-3805-ML				Sound	Some raveling	Fair
43-3805-LL				Sound	Some raveling	Fair
13-3740-ST	6.97	4.0	Screeded	Sound	Map cracking	Very poor
13-3740-SM				Sound	Map cracking	Very poor
13-3740-SL				Sound	Map cracking	Very poor
13-3755-TL	6.87	4.0	Form lining A	Sound	Slight scaling and spalling	Sound
13-3755-ML				Sound	Moderate spalling	Sound
13-3755-LL				Sound	Moderate spalling	Sound

Admixture N Study*

In March 1942, six concrete columns containing admixture N and six without admixture N were installed on the exposure rack at Treat Island, Maine.

The purpose of this installation was to determine the durability of concrete containing admixture N as compared with that of concrete containing a resin.

The 12 concrete columns (6 by 6 by 48 in.) represented four test conditions: plain portland cement, resin-treated portland cement, plain portland cement with admixture N, and resin-treated portland cement with admixture N. The addition of admixture N was made at the rate of 1% by weight of cement. A cement factor of 5.5 bags per cu yd was used for all concrete mixtures. The aggregates were natural sand and 1-in. maximum size natural gravel; a sand-aggregate ratio of 40% was used for all specimens. Water-cement ratios ranged from 5.7 to 6.25 gal per bag.

Table 1-PP lists these specimens and gives their exposure record along with other pertinent information.

This exposure was discontinued in 1943, with six of the twelve specimens being returned to the laboratory for examination. In the one winter of exposure 10 of the 12 specimens had failed. The findings of this investigation were:

- a. The concrete made with admixture N did not develop resistance to freezing-and-thawing to a materially greater degree than did the comparable concrete without the admixture.
- b. The use of admixture N with portland cement containing a resin did not materially affect the durability of the concrete.
- c. The aggregate used in the concrete of this series was preponderantly soft, showed evidence of cracks, and was definitely of poor quality.
- d. The inability of the concrete made with resin-treated cement to withstand a longer exposure on the Treat Island rack indicates that the presence of entrained air resulting from the use of the resin cannot necessarily be expected to protect concrete containing unsound aggregates.

* See Central Concrete Laboratory, Corps of Engineers, Preliminary Report, Series CR-PP (17 April 1942) and Addendum No. 1 to Preliminary Report, Series CR-PP (9 March 1943).

Table 1-PP

Program 4

Record of Testing of Concrete Columns With and Without Admixture N

1942-1943 (Installed March 1942)

Specimen No.	Cement and Admixture	0 Cycles Mar 1942 %E	10 Cycles Apr 1942 %E	198 Cycles 1943 %E
PP-12-1	Type II cement	100	105	Failed (at 172 cycles)
PP-12-2		100	104	Failed (at 114 cycles)
PP-12-3		100	104	Failed (at 152 cycles)
PP-13-2	Type II cement + resin	100	105	Failed (at 198 cycles)*
PP-13-3		100	103	Failed (at 198 cycles)*
PP-13-4		100	104	Failed (at 198 cycles)*
PP-15-1	Type II cement + admixture N	100	107	Failed (at 114 cycles)
PP-15-3		100	106	Failed (at 114 cycles)
PP-15-4		100	105	Failed (at 114 cycles)
PP-17-1	Type II cement + resin + admixture N	100	103	113*
PP-17-2		100	101	Failed (at 198 cycles)*
PP-17-4		100	103	65*

* Returned to laboratory.

Stewart Field Spheres*

In October 1943, 93 concrete spheres (12 in. in diameter) were installed on the Treat Island exposure rack. The purpose of this installation was to study the effect of different types of aggregates proposed for use at Stewart Field, Newburgh, N. Y., on the durability of concrete, and to investigate the use of spherical specimens in studies of concrete durability.

The aggregates consisted of natural sands, a manufactured sand, gravel, and crushed dolomite. Ten sand-aggregate combinations and three water-cement ratios (4.5, 5.0, and 5.5 gal per bag) were used in the mixes. Cement factors ranged from 4.9 to 7.6 bags per cu yd, and an air-entraining cement was used for all specimens.

Attempts were made to test these specimens for fundamental frequency, but these attempts were unsuccessful. The inspection of the specimens was therefore limited to visual examination and tapping to locate "dead spots."

In May 1949, after approximately 600 cycles of freezing-and-thawing, all specimens appeared to be in excellent condition, except for very localized scaling and spalling. However, tapping revealed that some of the specimens had "dead spots," i.e., localized areas where the concrete was probably internally deteriorated.

In June 1949, due to the need for additional space on the exposure rack, exposure of this group was discontinued, and the specimens were removed from the half-tide elevation.

Table 1-SFP lists the spheres and gives their exposure record along with other pertinent information.

In order to differentiate the durabilities of the various mixtures, the specimens were rated by use of the numerical rating system shown below. The individual ratings are given in table 1-SFP.

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* See Central Concrete Laboratory, Corps of Engineers, Concrete Investigation, Stewart Field, Newburgh, N. Y.; First Interim Report (20 March 1943); Second Interim Report (21 April 1943); and Final Report (April 1944).

Program 5

Specimen Condition	Numerical Rating	Specimen Condition	Numerical Rating
Sound	100	One crack	85
Scaling	95	Several dead spots	70
One dead spot	90	Cracking	60
Spalling	85		

Note: Ratings other than those shown above resulted from combinations of these ratings.

To facilitate comparisons between mixtures, average ratings are given below:

Aggregate Combination	Water-Cement Ratio gal per bag	No. of Specimens	Average Final Numerical Rating
Natural sand A + natural gravel A	4.5	7	93
Natural sand A + natural gravel A	5.0	6	99
Natural sand A + natural gravel A	5.5	6	83
Crushed + natural gravel A	4.5	2	95
Crushed + natural gravel A	5.0	2	100
Crushed + natural gravel A	5.5	2	98
Natural sand B + natural gravel A	4.5	4	93
Natural sand B + natural gravel A	5.0	4	99
Natural sand B + natural gravel A	5.5	4	79
Blend D + natural gravel A	4.5	1	100
Blend D + natural gravel A	5.0	1	100
Blend D + natural gravel A	5.5	1	100
Blend C + natural gravel A	5.0	1	70
Blend B + natural gravel A	4.5	1	100
Blend B + natural gravel A	5.0	1	100
Blend B + natural gravel A	5.5	1	90
Blend A + natural gravel A	5.0	3	93
Blend A + natural gravel A	5.5	3	89
Natural sand A + rock C	4.5	3	97
Natural sand A + rock C	5.0	2	100
Natural sand A + rock C	5.5	2	93
Crushed + rock C	4.5	3	97
Crushed + rock C	5.0	3	77
Crushed + rock C	5.5	3	87
Natural sand B + rock C	4.5	4	94
Natural sand B + rock C	5.0	3	77
Natural sand B + rock C	5.5	3	85

(Continued)

Program 5

Aggregate Combination	Water-Cement Ratio gal per bag	No. of Specimens	Average Final Numerical Rating
Blend D + rock C	4.5	1	90
Blend D + rock C	5.0	1	90
Blend C + rock C	4.5	2	95
Blend C + rock C	5.0	2	80
Blend C + rock C	5.5	1	65
Blend A + rock C	4.5	3	87
Blend A + rock C	5.0	3	83
Blend A + rock C	5.5	3	93
	Total	92	
	Dummy	1	
		93	

Table 1-SFP

Program 5

Effects of Exposure on Concrete Spheres Made with Various Aggregates Proposed for Use at Stewart Field, N. Y.

1943-1949 (Installed October 1943)

Specimen No.	Aggregate Combination Fine	Aggregate Combination Coarse	WC Ratio gal/bag	Cement Factor bags/cu yd Theo*	Cement Factor bags/cu yd Actual	Slump in.	Unit Weight lb Theo*	Unit Weight lb Actual	Air Content %	0 Cycles 1943 Condition	Approximately 600 Cycles 1949, Final Condition	Final Rating
11-A	Natural	Natural	4.5	7.4	7.18	2-1/2	149.5	144.7	3.2	Sound	Scaling, small crack	80
11-B	sand A	gravel		7.4	7.12	2-1/2	149.5	143.6	4.0	Sound	Sound	100
11-D		A		7.2	7.90	1-1/2	150.0	145.8	2.8	Sound	Scaling	95
11-E				7.2	6.96	3	150.0	144.7	3.5	Sound	Sound	100
11-F				7.2	6.99	2-1/2	150.0	145.5	3.0	Sound	One dead spot	90
11-G				7.2	7.00	2-1/4	150.0	145.7	2.9	Sound	Spalling	85
11-H				7.2	6.99	2-3/4	150.0	145.5	3.0	Sound	Sound	100
12-A	Natural	Natural	5.0	6.5	6.24	2-3/4	149.5	143.2	4.2	Sound	Sound	100
12-B	sand A	gravel		6.5	6.24	2-3/4	149.5	143.1	4.3	Sound	Sound	100
12-D		A		6.3	6.16	3	149.5	146.0	2.3	Sound	Sound	100
12-E				6.3	6.15	1-3/4	149.5	145.8	2.5	Sound	Sound	100
12-F				6.3	6.18	2-3/4	149.5	146.5	2.0	Sound	Sound	100
12-G				6.3	6.15	2-1/4	149.5	145.8	2.5	Sound	Scaling	95
13-A	Natural	Natural	5.5	5.60	5.28	2-1/2	151.0	142.0	6.0	Sound	One dead spot	90
13-B	sand A	gravel		5.60	5.29	2-1/2	151.0	142.2	5.8	Sound	Several dead spots, scaling	65
13-D		A		5.4	5.26	2-3/4	150.1	143.0	4.7	Sound	Sound	100
13-E				5.4	5.20	2-1/2	150.1	144.3	3.9	Sound	Several dead spots, scaling	65
13-F				5.4	5.19	3	150.1	144.0	4.0	Sound	Scaling, spalling	80
13-G				5.4	5.20	2-1/2	150.1	144.4	3.8	Sound	Sound	100
21-A	Crushed	Natural	4.5	7.6	7.28	2-3/4	151.5	144.7	4.5	Sound	One dead spot	90
21-B		gravel		7.6	7.29	2-1/2	151.5	144.9	4.3	Sound	Sound	100
		A										
22-A	Crushed	Natural	5.0	6.75	6.44	2-3/4	150.8	143.5	4.8	Sound	Sound	100
22-B		gravel		6.75	6.44	2-1/2	150.8	143.7	4.7	Sound	Sound	100
		A										
23-A	Crushed	Natural	5.5	5.85	5.60	2-1/2	151.5	144.7	4.5	Sound	Scaling	95
23-B		gravel		5.85	5.59	2-1/2	151.5	144.5	4.6	Sound	Sound	100
		A										
31-A	Natural	Natural	4.5	7.0	6.69	2-1/2	151.0	144.0	4.6	Sound	Several dead spots	70
31-D	sand B	gravel		6.8	6.52	2-1/4	151.3	144.8	4.3	Sound	Sound	100
31-E		A		6.8	6.52	1-1/2	151.3	145.0	4.2	Sound	Sound	100
31-F				6.8	6.53	1-1/2	151.3	145.1	4.1	Sound	Sound	100
32-A	Natural	Natural	5.0	6.2	5.84	2-1/4	150.8	141.5	6.2	Sound	Sound	100
32-D	sand B	gravel		6.0	6.02	2	151.2	146.7	3.0	Sound	Scaling	95
32-E		A		6.0	6.01	2-1/2	151.2	146.4	3.2	Sound	Sound	100
32-F				6.0	6.03	1-1/2	151.2	147.0	2.8	Sound	Sound	100
33-A	Natural	Natural	5.5	5.4	5.11	2-1/2	151.0	142.5	5.6	Sound	Scaling	95
33-D	sand B	gravel		5.2	4.96	2-1/2	151.3	144.4	4.8	Sound	Scaling	95
33-E		A		5.2	5.04	1-1/4	151.3	146.0	3.2	Sound	Scaling	95
33-F				5.2	5.03	1	151.3	146.1	3.4	Sound	Cracked, one dead spot, scaling, spalling	30
41-A	Blend D	Natural	4.5	7.45	7.25	2-1/2	150.1	145.2	2.7	Sound	Sound	100
		gravel										
		A										
42-A	Blend D	Natural	5.0	6.40	6.09	2-1/2	151.3	143.8	5.0	Sound	Sound	100
42-D	Blend C	gravel		6.20	5.88	2-1/2	153.8	145.4	5.5	Sound	Several dead spots	70
		A										
43-A	Blend D	Natural	5.5	5.6	5.38	2-1/2	150.3	144.3	4.0	Sound	Sound	100
		gravel										
		A										
51-A	Blend B	Natural	4.5	7.25	6.99	2-1/2	150.0	144.3	3.8	Sound	Sound	100
		gravel										
		A										
52-A	Blend B	Natural	5.0	6.3	6.04	2-1/2	150.0	143.4	4.4	Sound	Sound	100
52-D	Blend A	gravel		6.1	5.87	2-3/4	150.8	145.0	3.8	Sound	One dead spot, scaling	85
52-E	Blend A	A		6.1	5.81	1-3/4	150.8	145.9	3.2	Sound	One dead spot	90
52-F	Blend A			6.1	5.84	3-1/4	150.8	144.0	4.5	Sound	Scaling	95
53-A	Blend B	Natural	5.5	5.50	5.23	2-1/2	150.1	142.5	5.1	Sound	One dead spot	90
53-D	Blend A	gravel		5.3	5.08	3	150.8	144.2	4.4	Sound	One dead spot	90
53-E	Blend A	A		5.3	5.08	3	150.8	144.3	4.3	Sound	One dead spot, spalling	75
53-F	Blend A			5.3	5.14	1-3/4	150.8	145.9	3.2	Sound	Sound	100

(Continued)

Theo denotes theoretical.

Program 5

Table 1-SFP (Concluded)

Specimen No.	Aggregate Combination Fine	Aggregate Combination Coarse	WC Ratio gal/bag	Cement Factor bags/cu yd Theo	Cement Factor bags/cu yd Actual	Slump in.	Unit Weight lb Theo	Unit Weight lb Actual	Air Content %	0 Cycles 1943 Condition	Approximately 600 Cycles 1949, Final Condition	Final Rating
61-A	Natural	Rock C	4.5	7.7	7.48	2-1/4	154.7	149.1	3.0	Sound	Sound	100
61-D	sand A			7.5	7.36	2-1/2	155.3	152.4	1.9	Sound	Sound	100
61-E				7.5	7.34	2	155.3	152.1	2.1	Sound	One dead spot	90
62-A	Natural	Rock C	5.0	6.80	6.44	2-1/2	154.6	146.0	5.5	Sound	Sound	100
62-D	sand A			6.60	6.40	3	155.3	150.4	3.1	Sound	Sound	100
63-A	Natural	Rock C	5.5	5.90	5.66	2-1/2	154.9	148.2	4.3	Sound	One dead spot, scaling	85
63-D	sand A			5.70	5.50	2-1/2	156.0	150.4	3.6	Sound	Sound	100
71-A	Crushed	Rock C	4.5	7.95	7.45	2-1/2	156.6	146.0	6.8	Sound	One dead spot	90
71-B				7.95	7.43	2-1/2	156.6	145.6	7.0	Sound	Sound	100
71-D				7.80	7.61	2-1/2	157.0	153.1	2.5	Sound	Sound	100
72-A	Crushed	Rock C	5.0	7.00	6.65	2-1/2	156.5	148.2	5.3	Sound	One dead spot, cracking	50
72-D				6.80	6.63	2-1/2	157.2	153.3	2.5	Sound	One dead spot	90
72-E				6.80	6.58	2	157.2	151.9	3.4	Sound	One dead spot	90
73-A	Crushed	Rock C	5.5	6.15	5.80	2-3/4	156.8	147.2	6.1	Sound	One dead spot	90
73-D				6.0	5.84	1-3/4	157.4	152.8	2.9	Sound	One dead spot, scaling	85
73-E				6.0	5.81	2-1/2	157.4	152.0	3.4	Sound	One dead spot, scaling	85
81-A	Natural	Rock C	4.5	7.35	7.01	2-1/4	156.5	148.8	4.9	Sound	Sound	100
81-D	sand B			7.10	6.86	1-3/4	157.1	151.4	3.6	Sound	One dead spot	90
81-E				7.10	6.83	2-1/2	157.1	151.0	3.9	Sound	Spalling	85
81-F				7.10	6.84	2-1/2	157.1	151.1	3.8	Sound	Sound	100
82-A	Natural	Rock C	5.0	6.5	6.10	2-3/4	156.4	146.8	6.5	Sound	One dead spot	90
82-D	sand B			6.2	5.97	1-3/4	157.8	151.7	3.9	Sound	One dead spot	90
82-E				6.2	5.95	2-1/4	157.8	151.3	4.2	Sound	One dead spot, cracking	50
83-A	Natural	Rock C	5.5	5.75	5.34	2-1/2	156.6	144.5	7.7	Sound	Slight scaling	95
83-D	sand B			5.50	5.29	1-3/4	157.3	150.8	4.1	Sound	One dead spot	90
83-E				5.50	5.29	1-1/2	157.3	151.2	3.9	Sound	Several dead spots	70
91-A	Blend D	Rock C	4.5	7.8	7.58	2-1/2	155.2	150.7	2.9	Sound	One dead spot	90
91-D	Blend C			7.6	7.31	1-1/2	157.0	151.2	3.8	Sound	Sound	100
91-E	Blend C			7.6	7.26	2-1/2	157.0	150.0	4.6	Sound	One dead spot	90
92-A	Blend D	Rock C	5.0	6.75	6.49	2-1/2	155.3	149.2	4.1	Sound	One dead spot	90
92-D	Blend C			6.55	6.31	2-1/2	157.1	152.5	3.9	Sound	Several dead spots	70
92-E	Blend C			6.55	6.31	2-1/2	157.1	152.6	3.9	Sound	One dead spot	90
93-D	Blend C	Rock C	5.5	5.90	5.76	2-1/4	157.1	153.3	2.5	Sound	Several dead spots, scaling	65
101-D	Blend A	Rock C	4.5	7.5	7.15	2-3/4	156.3	148.8	4.8	Sound	Several dead spots	70
101-E				7.5	7.35	2-1/4	156.3	153.0	2.1	Sound	Sound	100
101-F				7.5	7.36	1-3/4	156.3	153.3	1.9	Sound	One dead spot	90
102-D	Blend A	Rock C	5.0	6.40	6.10	1-3/4	156.8	148.9	5.0	Sound	One dead spot	90
102-E				6.40	6.03	3-3/4	156.8	147.2	6.1	Sound	One dead spot	90
102-F				6.40	6.17	2-1/2	156.8	150.8	3.8	Sound	Several dead spots	70
103-D	Blend A	Rock C	5.5	5.70	5.43	2-1/2	156.9	149.0	5.0	Sound	Slight spalling	85
103-E				5.70	5.46	3	156.9	149.8	4.5	Sound	Scaling	95
103-F				5.70	5.47	3	156.9	150.2	4.3	Sound	Sound	100
	Dummy specimen		---	--	--	---	---	---	---	Sound	Sound	100

Upper Narrows Dam Specimens

In January 1944, nine (6 in. in diameter by 12 in. long) concrete cores from Upper Narrows Dam, near Smartville, California, were installed on the exposure rack at Treat Island. The purpose of this installation was to determine, by means of natural freezing-and-thawing, the durability of the Upper Narrows Dam concrete as affected by the aggregates.

The cores were drilled from the downstream face of the dam. One inch of each end of each core was embedded in a pad of concrete containing entrained air to prevent deterioration of the circumferential edge progressing into the body of each core, and also to facilitate installation.

For comparison purposes, nine shot-drilled cores were taken from Stewart Field and Rye Lake Airports, N. Y., and placed on the exposure rack on the same date (six cores from Stewart Field, three from Rye Lake). The air-entrained concrete from which the cores were drilled contained the following types of aggregate:

Project	Cores	Fine Aggregate	Coarse Aggregate
Stewart Field roads	3	Glacial sand	Crushed dolomite
Stewart Field runways	3	Siliceous sand	Crushed dolomite
Rye Lake Airport	3	Siliceous sand	Crushed granite gravel

Table 1-UNDP lists the Upper Narrows cores and gives their exposure record; all of the cores from the Upper Narrows Dam had failed after 535 cycles (five winters of exposure).

Failure of these cores was apparently due to differential expansion.

The nine cores installed for comparison (Stewart and Rye Lake) remained sound after 13 winters (1499 cycles) and were discarded in 1956.

Table 1-UNDP Program 6

Record of Testing of Concrete Cores from Upper Narrows Dam

1944-1948 (Installed January 1944)

Specimen No.	0 Cycles 1944 Condition	181 Cycles 1945 Condition	286 Cycles 1946 Condition	535 Cycles 1948 Condition (Final)
1A	Sound	Sound	Failed	
1C	Sound	Sound	Failed	
2B	Sound	Sound	Failed	
3A	Sound	Sound	Sound	Failed
4A	Sound	Sound	Failed	
4B	Sound	Sound	Failed	
5B	Sound	Sound	Failed	
5C	Sound	Sound	Failed	
6A	Sound	Failed		

Curing Media Study

The purpose of this program was to study the effect of curing media on the durability of concrete.

Specimens

In February 1943, 300 concrete specimens (3-1/2 by 4-1/2 by 20 in.) were installed on the exposure rack at Treat Island, Maine. These specimens had been sawed from 3-1/2- by 20- by 20-in. laboratory slabs at the expiration of the curing period. The following types of curing were employed:

- a. Ten different proprietary membrane curing compounds
- b. Water
- c. Air (alone)
- d. Special paper
- e. Admixture A + air

Six additional admixtures and cement containing a resin were also used to provide additional information. The characteristics of the concrete mixtures were as follows:

	Plain Cement Concrete	Concrete with Admixture
Water-cement ratio, gal per bag	7.0	6.6
Cement factor, bags per cu yd	5.6	5.6
Slump, in.	2-1/2	1/2-6-1/2
Sand:Aggregate, % by volume	44	44
Mixture proportions	1:2.64:3.70	1:2.68:3.74

The specimens represented concrete placed in thin horizontal members cast on forms (floors or bridge decks), thin sections placed on damp earth (roads or runways), and thin vertically cast sections (walls or parapets). The thin slabs cast on moist earth were placed on compacted sandy loam 14 in. deep. Three types of form linings, designated A, B, and C, were used on the vertical specimens.

Exposure

The specimens were originally installed in 100 wooden boxes (3 per

box) in such a manner that only the finished or formed 4-1/2- by 20-in. face of each specimen was exposed to weathering. One hundred twenty-four of the specimens were cast horizontally against the dry and moist soil bases, and one hundred seventy-four were cast vertically with surfaces formed against the three types of form linings. Two beams were dummy specimens used to complete a box of three and were not under test.

In May 1947, to accelerate the effects of the exposure and to permit differentiations in the durabilities of the various mixtures to be seen, the specimens were removed from the boxes and placed on the exposure rack so that they were exposed to weathering effects on all surfaces.

After the winter of 1957-1958, exposure of the remaining specimens was discontinued.

Table 1-CRMA gives the exposure record of all specimens exposed in this series, along with other pertinent information.

Summary of Findings

After 15 winters of exposure (1793 cycles of freezing-and-thawing), 169 specimens remained of the 298 exposed. This amounts to a percentage failure of 43%.

To summarize further:

	No. of Specimens Installed	No. of Specimens Remaining in 1958	% Failure
Specimens Cast Horizontally vs Specimens Cast Vertically			
Specimens cast horizontally	124	72	42
Specimens cast vertically	174	97	44
Plain Concrete vs Concrete with Admixture			
Plain concrete	186	68	63
Concrete with admixture	112	101	10
Soil Base vs Dry Base			
Surface cast on soil base	63	46	27
Surface cast on dry base	61	26	57

(Continued)

	No. of Specimens Installed	No. of Specimens Remaining in 1958	% Failure
Form Linings			
Surface cast against:			
Form lining A	58	31	47
Form lining B	58	34	41
Form lining C	58	32	45
Admixtures			
Resin	15	15	0
Admixture A	15	13	13
Admixture B	11	11	0
Admixture C	15	15	0
Admixture D	15	15	0
Admixture E	15	15	0
Admixture F	11	11	0
Admixture G	15	6	60
All Curing Methods			
Cure:			
Water	112	92	18
Air (alone)	15	11	27
Special paper	6	2	67
Proprietary membrane curing compounds	150	51	66
Air + admixture A	15	13	13
Proprietary Membrane Curing Compounds			
Compound 1	15	10	33
Compound 2	15	5	67
Compound 3	15	2	87
Compound 4	15	4	73
Compound 5	15	1	93
Compound 6	15	6	60
Compound 7	15	6	60
Compound 8	15	11	27
Compound 9	15	3	80
Compound 10	15	3	80

Conclusions

It was concluded from this investigation that:

a. Specimens cast vertically had a slightly higher percentage of failure than specimens cast horizontally (44% vs 42%).

b. Specimens made of concrete with admixtures had a considerably lower percentage of failure than those made with plain concrete (10% vs 63%).

c. Specimens cast on a dry base had a considerably higher percentage of failure than those cast on moist soil base (57% vs 27%).

d. Percentage of failure was approximately the same among form-lined specimens with the order of durability being: form lining B (41%), form lining C (45%), and form lining A (47%).

e. Specimens containing admixtures B, C, D, E, F, and resin had excellent durability, with no failures at all. Specimens containing admixture G had a very high percentage of failure (60%), and those containing admixture A had 13%.

f. Specimens cured with water (18%) or air (alone) (27%) had considerably lower percentages of failure than specimens cured with proprietary membrane curing compounds (66%) or special paper (67%). Specimens cured with air plus admixture A had a percentage failure of only 13%.

g. Of the specimens containing proprietary membrane curing compounds, compounds 1 (33%) and 8 (27%) showed the smallest percentages of failure, with No. 8 showing the best durability. The others were: compounds 6 and 7 (60%), compound 2 (67%), compound 4 (73%), compounds 9 and 10 (80%), compound 3 (87%), compound 5 (93%).

Table 1-CRMA Program 7

Record of Testing of Concrete Beams Cured by Various Media

1943-1958 (Installed February 1943)

Specimen No.	Surface Cast on or Against	Admixture	Curing Medium	0 Cycles 1943 %E	210 Cycles 1944 %E	483 Cycles 1947 %E	614 Cycles 1948* %E	719 Cycles 1949 %E	880 Cycles 1950 %E	969 Cycles 1951 %E
			Horizontally Cast Specimens							
EAS-1B	Soil base	None	Compound 1	100	115	128	128	124	125	125
EBS-1B				100	103	125	120	119	141	128
EAS-1C				100	112	130	127	125	127	129
EAH-1B	Dry base	None	Compound 1	100	112	186	81	Failed		
EAH-1C				100	112	186	54	Failed		
EBH-1B				100	106	163	118	121	125	124
EAS-2B	Soil base	None	Compound 2	100	107	102	54	Failed		
EBS-2B				100	105	122	103	105	108	110
EAS-2C				100	112	130	125	125	124	120
EAH-2B	Dry base	None	Compound 2	100	112	141	146	141	141	143
EAH-2C				100	108	126	64	Failed		
EBH-2B				100	103	130	125	122	126	126
EAS-3B	Soil base	None	Compound 3	100	103	126	123	122	123	125
EBS-3B				100	108	130	117	119	116	119
EAS-3C				100	108	130	123	125	123	121
EAH-3B	Dry base	None	Compound 3	100	121	131	56	Failed		
EAH-3C				100	112	129	80	Failed		
EBH-3B				100	106	126	122	123	124	130
EAS-4B	Soil base	None	Compound 4	100	113	125	125	123	121	121
EBS-4B				100	108	141	136	128	134	132
EAS-4C				100	113	128	118	118	114	111
EAH-4B	Dry base	None	Compound 4	100	110	126	119	119	119	119
EAH-4C				100	113	128	128	126	126	126
EBH-4B				100	106	123	120	120	124	134
EAS-5B	Soil base	None	Compound 5	100	110	132	Failed			
EBS-5B				100	103	126	119	123	124	124
EAS-5C				100	111	126	127	127	128	130
EAH-5B	Dry base	None	Compound 5	100	110	121	Failed			
EAH-5C				100	107	130	85	67	Failed	
EBH-5B				100	108	127	127	125	Failed	
EAS-6B	Soil base	None	Compound 6	100	110	122	135	132	135	137
EBS-6B				100	108	130	95	92	79	74
EAS-6C				100	107	130	122	125	124	127
EAH-6B	Dry base	None	Compound 6	100	116	151	151	154	152	157
EAH-6C				100	116	133	123	125	119	122
EBH-6B				100	110	129	123	121	124	125
EAS-7B	Soil base	None	Compound 7	100	107	131	124	128	129	130
EBS-7B				100	103	106	98	98	105	102
EAS-7C				100	106	136	111	111	113	113
EAH-7B	Dry base	None	Compound 7	100	108	154	152	149	145	147
EAH-7C				100	108	121	110	110	106	92
EBH-7B				100	108	126	152	148	147	147
EAS-8B	Soil base	None	Compound 8	100	110	137	136	136	135	135
EBS-8B				100	111	134	129	129	128	129
EAS-8C				100	111	137	134	132	135	136
EAH-8B	Dry base	None	Compound 8	100	120	138	131	127	132	159
EAH-8C				100	120	135	107	100	98	138
EBH-8B				100	120	139	132	129	130	132
EAS-9B	Soil base	None	Compound 9	100	111	115	115	133	130	130
EBS-9B				100	100	136	52	52	Failed	
EAS-9C				100	107	123	123	121	122	124
EAH-9B	Dry base	None	Compound 9	100	117	139	131	127	121	121
EAH-9C				100	120	139	137	137	134	135
EBH-9B				100	109	145	143	143	142	143
EAS-10B	Soil base	None	Compound 10	100	111	129	120	125	133	134
EBS-10B				100	108	139	138	139	137	139
EAS-10C				100	107	134	133	133	132	132
EAH-10B	Dry base	None	Compound 10	100	110	131	116	121	114	114
EAH-10C				100	110	133	100	112	91	87
EBH-10B				100	106	128	114	125	131	136
EAS-11B	Soil base	None	Water	100	110	137	134	134	133	132
EBS-11B				100	111	134	126	129	136	140
EAS-11C				100	114	140	100	139	138	140

(Continued)

* Specimens were removed from boxes in winter of 1947-1948 and placed on exposure rack exposed to weathering effects on all surfaces.

Table 1-CRMA (Continued)

Specimen No.	Surface Cast on or Against	Admixture	Curing Medium	0 Cycles 1943 %E	210 Cycles 1944 %E	483 Cycles 1947 %E	614 Cycles 1948 %E	719 Cycles 1949 %E	880 Cycles 1950 %E	969 Cycles 1951 %E
			Horizontally Cast Specimens (Continued)							
EAH-11B	Dry base	None	Water	100	116	134	62	80	Failed	
EAH-11C				100	116	136	143	120	Failed	
EBH-11B				100	106	125	119	124	124	127
EAS-12B	Soil base	None	Air	100	120	150	146	146	147	149
EBS-12B				100	111	134	130	131	130	131
EAS-12C				100	125	150	148	148	148	149
EAH-12B	Dry base	None	Air	100	130	155	149	151	149	147
EAH-12C				100	128	160	160	160	163	165
EBH-12B				100	137	158	154	154	152	152
EAS-13B	Soil base	B	Water	100	122	137	135	135	134	134
EBS-13B				100	112	130	129	129	131	131
EAS-13C				100	125	136	134	134	136	134
EAH-13B	Dry base	B	Water	100	116	135	133	133	133	133
EAH-13C				100	120	136	136	135	134	134
EAP-2B	Dummy specimen			---	---	---	---	---	---	---
EAS-14B	Soil base	C	Water	100	115	133	127	129	131	131
EBS-14B				100	111	138	136	137	138	138
EAS-14C				100	125	144	144	144	142	142
EAH-14B	Dry base	C	Water	100	127	141	133	135	137	135
EAH-14C				100	120	135	133	135	135	135
EBH-14B				100	100	129	126	126	125	125
EAS-15B	Soil base	D	Water	100	114	136	132	132	131	131
EBS-15B				100	106	123	121	123	126	127
EAS-15C				100	114	152	144	146	144	147
EAH-15B	Dry base	D	Water	100	117	134	130	132	135	135
EAH-15C				100	116	136	132	132	134	134
EBH-15B				100	110	131	126	128	128	129
EAS-16B	Soil base	E	Water	100	121	138	136	136	134	135
EBS-16B				100	111	134	128	129	127	127
EAS-16C				100	122	137	131	133	132	134
EAH-16B	Dry base	E	Water	100	126	136	132	132	131	131
EAH-16C				100	126	138	136	136	133	133
EBH-16B				100	109	125	119	121	119	120
EAS-17B	Soil base	F	Water	100	120	140	138	136	140	140
EBS-17B				100	117	133	126	130	130	131
EAS-17C				100	121	142	138	140	140	140
EAH-17B	Dry base	F	Water	100	132	139	134	134	137	135
EAH-17C				100	132	143	139	141	139	139
EAR-2C	Dummy specimen			---	---	---	---	---	---	---
EAS-18B	Soil base	A	Air	100	126	152	148	150	151	153
EBS-18B			(Admixture A)	100	114	136	130	132	133	134
EAS-18C				100	117	146	139	143	143	143
EAH-18B	Dry base	A	Air	100	125	143	138	142	139	139
EAH-18C			(Admixture A)	100	125	145	143	145	143	143
EBH-18B				100	152	148	169	171	174	179
EAS-19B	Soil base	Resin	Water	100	114	138	130	132	134	136
EBS-19B				100	112	134	127	131	131	132
EAS-19C				100	115	137	135	138	138	140
EAH-19B	Dry base	Resin	Water	100	122	137	133	135	152	152
EAH-19C				100	124	136	138	131	129	129
EBH-19B				100	114	138	127	129	126	128
EAS-20B	Soil base	G	Water	100	111	114	134	135	136	137
EBS-20B				100	110	131	121	126	121	122
EAS-20C				100	112	138	135	136	136	136
EAH-20B	Dry base	G	Water	100	110	134	127	131	98	102
EAH-20C				100	114	134	133	134	133	133
EBH-20B				100	107	128	118	122	117	119
EAS-21B	Soil base	None	Special paper	100	114	140	133	137	136	138
EBS-21B				100	107	115	89	97	83	84
EAS-21C				100	115	140	135	135	136	137
EAH-21B	Dry base	None	Special paper	100	116	156	142	149	155	157
EAH-21C				100	115	129	76	84	60	47 Fail.
EBH-21B				100	110	128	112	118	116	124
			Vertically Cast Specimens							
EAC-1B	Form lining A	None	Compound 1	100	131	145	143	137	132	132
EAC-1C				100	131	141	131	135	134	136
EBC-1B				100	122	133	125	124	113	113

(Continued)

Specimen No.	Surface Cast on or Against	Admixture	Curing Medium	0 Cycles 1943 %E	210 Cycles 1944 %E	483 Cycles 1947 %E	614 Cycles 1948 %E	719 Cycles 1949 %E	880 Cycles 1950 %E	969 Cycles 1951 %E
			Vertically Cast Specimens (Continued)							
EAR-1B	Form lining B	None	Compound 1	100	125	141	131	133	132	132
EAR-1C				100	125	137	131	133	133	132
EBR-1B				100	112	128	118	118	113	115
EAP-1B	Form lining C	None	Compound 1	100	131	139	133	137	134	135
EAP-1C				100	125	141	129	131	131	114
EBP-1B				100	127	137	129	129	131	133
EAC-2AB	Form lining A	None	Compound 2	100	121	132	126	126	126	128
EAC-2AC				100	119	129	117	119	120	119
EBC-2B				100	120	127	118	120	111	113
EAP-2AB	Form lining C	None	Compound 2	100	120	136	129	131	129	133
EAP-2AC				100	120	138	127	129	127	131
EBP-2B				100	130	147	138	140	140	142
EAR-2AB	Form lining B	None	Compound 2	100	108	126	118	118	111	115
EAR-2AC				100	108	124	118	113	111	113
EBR-2B				100	116	127	113	111	103	102
EAC-3B	Form lining A	None	Compound 3	100	120	139	129	125	106	99
EAC-3C				100	115	128	123	121	100	107
EBC-3B				100	118	140	123	125	105	97
EAR-3B	Form lining B	None	Compound 3	100	117	131	124	114	89	89
EAR-3C				100	117	131	124	85	90	Failed
EBR-3B				100	112	126	116	119	96	93
EAP-3B	Form lining C	None	Compound 3	100	127	140	133	127	108	103
EAP-3C				100	127	142	129	131	113	129
EBP-3B				100	120	133	127	131	125	123
EAC-4B	Form lining A	None	Compound 4	100	125	138	133	129	113	112
EAC-4C				100	123	136	130	130	125	130
EBC-4B				100	117	136	128	130	125	129
EAR-4B	Form lining B	None	Compound 4	100	124	134	126	119	100	94
EAR-4C				100	120	134	129	125	91	85
EBR-4B				100	116	123	118	120	113	113
EAP-4B	Form lining C	None	Compound 4	100	138	149	140	134	112	110
EAP-4C				100	130	145	138	138	130	134
EBP-4B				100	127	137	131	129	124	129
EAC-5B	Form lining A	None	Compound 5	100	120	134	134	116	109	108
EAC-5C				100	121	132	126	128	126	126
EBC-5B				100	118	142	128	104	Failed	
EAR-5B	Form lining B	None	Compound 5	100	116	131	127	127	93	90
EAR-5C				100	116	133	122	115	84	81
EBR-5B				100	115	133	73	Failed		
EAP-5B	Form lining C	None	Compound 5	100	125	137	137	141	126	124
EAP-5C				100	120	131	124	118	83	70
EBP-5B				100	116	127	80	Failed		
EAC-6B	Form lining A	None	Compound 6	100	138	162	147	147	145	147
EAC-6C				100	133	157	141	141	137	137
EBC-6B				100	123	138	130	119	119	90
EAR-6B	Form lining B	None	Compound 6	100	129	143	139	139	132	136
EAR-6C				100	135	143	139	139	132	132
EBR-6B				100	120	133	129	131	128	127
EAP-6B	Form lining C	None	Compound 6	100	145	159	152	155	154	155
EAP-6C				100	136	159	152	150	148	145
EBP-6B				100	126	143	138	138	126	123
EAC-7B	Form lining A	None	Compound 7	100	120	133	129	131	130	130
EAC-7C				100	116	133	126	128	126	127
EBC-7B				100	123	132	126	128	115	111
EAR-7B	Form lining B	None	Compound 7	100	115	126	113	109	100	95
EAR-7C				100	116	129	122	120	114	114
EBR-7B				100	112	130	123	125	124	123
EAP-7B	Form lining C	None	Compound 7	100	126	130	108	Failed	103	99
EAP-7C				100	121	137	121	125	113	113
EBP-7B				100	124	141	131	135	134	134
EAC-8B	Form lining A	None	Compound 8	100	136	151	145	149	146	146
EAC-8C				100	136	151	145	145	146	146
EBC-8B				100	124	145	145	138	139	140
EAR-8B	Form lining B	None	Compound 8	100	143	159	152	152	154	151
EAR-8C				100	130	149	140	143	142	142
EBR-8B				100	124	143	136	138	129	131

Table 1-CRMA (Continued)

Specimen No.	Surface Cast on or Against	Admixture	Curing Medium	0 Cycles 1943 %E	210 Cycles 1944 %E	483 Cycles 1947 %E	614 Cycles 1948 %E	719 Cycles 1949 %E	880 Cycles 1950 %E	969 Cycles 1951 %E
			Vertically Cast Specimens (Continued)							
EAP-8B	Form lining C	None	Compound 8	100	153	174	167	163	169	169
EAP-8C				100	151	175	161	163	163	165
EBP-8B				100	148	159	155	155	143	143
EAC-9B	Form lining A	None	Compound 9	100	116	129	121	123	113	114
EAC-9C				100	116	129	125	125	123	125
EBC-9B				100	123	79	Failed			
EAR-9B	Form lining B	None	Compound 9	100	124	137	133	133	130	131
EAR-9C				100	115	126	121	119	113	115
EBR-9B				100	116	131	122	105	95	99
EAP-9B	Form lining C	None	Compound 9	100	133	143	137	139	125	102
EAP-9C				100	151	168	156	154	147	147
EBP-9B				100	131	146	142	144	136	139
EAC-10B	Form lining A	None	Compound 10	100	117	129	124	102	Failed	
EAC-10C				100	117	128	119	121	112	111
EBC-10B				100	121	Failed				
EAR-10B	Form lining B	None	Compound 10	100	111	126	117	68	Failed	
EAR-10C				100	117	130	121	123	119	121
EBR-10B				100	117	121	100	105	90	71
EAP-10B	Form lining C	None	Compound 10	100	137	153	128	70	Failed	
EAP-10C				100	137	153	142	135	123	121
EBP-10B				100	130	143	134	138	138	136
EAC-11B	Form lining A	None	Water	100	123	136	130	128	108	79
EAC-11C				100	122	136	130	126	115	110
EBC-11B				100	114	129	126	124	123	124
EAR-11B	Form lining B	None	Water	100	118	155	151	149	Failed	
EAR-11C				100	121	137	127	118	107	103
EBR-11B				100	115	130	122	123	122	118
EAP-11B	Form lining C	None	Water	100	124	151	138	124	74	Failed
EAP-11C				100	127	153	147	140	110	78
EBP-11B				100	127	139	131	133	133	135
EAC-12B	Form lining A	None	Air	100	135	153	147	147	148	148
EAC-12C				100	136	155	147	149	146	148
EBC-12B				100	137	155	151	151	147	153
EAR-12B	Form lining B	None	Air	100	137	153	149	147	145	145
EAR-12C				100	131	143	137	137	132	97
EBR-12B				100	135	155	145	147	147	147
EAP-12B	Form lining C	None	Air	100	137	156	143	137	Failed	
EAP-12C				100	144	159	152	146	100	92
EBP-12B				100	157	175	170	170	170	173
EAC-13B	Form lining A	B	Water	100	130	149	143	143	140	140
EAC-13C				100	136	134	130	130	129	129
EAR-13B	Form lining B	B	Water	100	120	133	122	122	118	120
EAR-13C				100	132	134	130	132	129	129
EAP-13B	Form lining C	B	Water	100	122	137	137	133	134	134
EAP-13C				100	122	133	129	131	130	130
EAC-14B	Form lining A	C	Water	100	142	142	138	136	136	136
EAC-14C				100	128	139	140	137	137	137
EBC-14B				100	111	125	122	120	121	122
EAR-14B	Form lining B	C	Water	100	138	136	133	131	130	128
EAR-14C				100	131	145	138	140	140	139
EBR-14B				100	108	123	121	116	115	117
EAP-14B	Form lining C	C	Water	100	136	140	138	138	137	137
EAP-14C				100	127	142	138	138	136	139
EBP-14B				100	108	122	117	116	114	116
EAC-15B	Form lining A	D	Water	100	122	137	126	126	124	126
EAC-15C				100	122	135	127	131	130	130
EBC-15B				100	123	125	121	119	122	124
EAR-15B	Form lining B	D	Water	100	116	132	125	128	124	124
EAR-15C				100	116	128	125	126	124	124
EBR-15B				100	111	124	118	118	118	85
EAP-15B	Form lining C	D	Water	100	126	137	134	136	125	135
EAP-15C				100	131	146	144	144	143	145
EBP-15B				100	118	132	123	127	125	126
EAC-16B	Form lining A	E	Water	100	127	138	136	136	132	132
EAC-16C				100	131	142	138	138	136	136
EBC-16B				100	120	124	122	120	118	118

(Continued)

Specimen No.	Surface Cast on or Against	Admixture	Curing Medium	0 Cycles 1943 %E	210 Cycles 1944 %E	483 Cycles 1947 %E	614 Cycles 1948 %E	719 Cycles 1949 %E	880 Cycles 1950 %E	969 Cycles 1951 %E
				Vertically Cast Specimens (Continued)						
EAR-16B	Form lining B	E	Water	100	127	138	133	131	130	131
EAR-16C				100	131	133	133	133	134	134
EBR-16B				100	124	135	124	126	125	133
EAP-16B	Form lining C	E	Water	100	134	144	141	141	141	141
EAP-16C				100	133	139	137	142	134	134
EBP-16B				100	120	126	122	124	122	123
EAC-17B	Form lining A	F	Water	100	133	145	140	140	138	138
EAC-17C				100	133	146	144	144	141	141
EAR-17B	Form lining B	F	Water	100	129	137	137	134	135	135
EAR-17C				100	129	137	132	134	130	132
EAP-17B	Form lining C	F	Water	100	139	147	142	145	140	143
EAP-17C				100	137	146	143	145	142	142
EAC-18B	Form lining A	A	Air (Admixture A)	100	126	142	140	138	134	136
EAC-18C				100	131	146	142	142	135	137
EBC-18B				100	126	141	137	137	112	120
EAR-18B	Form lining B	A	Air (Admixture A)	100	125	143	137	137	117	119
EAR-18C				100	125	141	135	133	126	126
EBR-18B				100	126	137	135	135	129	133
EAP-18B	Form lining C	A	Air (Admixture A)	100	138	156	151	151	147	149
EAP-18C				100	136	151	147	149	147	148
EBP-18B				100	135	152	148	143	144	148
EAC-19B	Form lining A	Resin	Water	100	127	138	131	133	130	130
EAC-19C				100	142	144	142	138	139	139
EBC-19B				100	120	126	124	122	124	124
EAR-19B	Form lining B	Resin	Water	100	121	138	130	130	129	131
EAR-19C				100	136	138	136	132	133	134
EBR-19B				100	118	127	119	118	117	119
EAP-19B	Form lining C	Resin	Water	100	132	148	143	143	140	142
EAP-19C				100	135	148	143	141	137	140
EBP-19B				100	124	137	132	133	133	136
EAC-20B	Form lining A	G	Water	100	121	136	133	115	130	Failed
EAC-20C				100	121	136	132	128	Failed	
EBC-20B				100	110	126	121	114	104	Failed
EAR-20B	Form lining B	G	Water	100	121	136	130	100	Failed	
EAR-20C				100	116	131	129	89	Failed	
EBR-20B				100	108	126	123	114	97	101
EAP-20B	Form lining C	G	Water	100	131	147	141	139	129	129
EAP-20C				100	131	145	145	141	135	139
EBP-20B				100	119	124	128	102	Failed	
				1070 Cycles 1952 %E	1155 Cycles 1953 %E	1266 Cycles 1954 %E	1411 Cycles 1955 %E	1578 Cycles 1956 %E	1722 Cycles 1957 %E	1793 Cycles (Final) 1958 %E
				Horizontally Cast Specimens						
EAS-1B	Soil base	None	Compound 1	128	130	130	134	140	142	144
EBS-1B				124	128	132	130	130	158	170
EAS-1C				132	134	141	141	148	148	157
EBH-1B	Dry base	None	Compound 1	129	132	135	131	131	124	126
EBS-2B	Soil base	None	Compound 2	121	Failed					
EAS-2C				127	129	133	139	149	Failed	
EAH-2B	Dry base	None	Compound 2	145	146	150	156	159	159	163
EBH-2B				133	Failed					
EAS-3B	Soil base	None	Compound 3	130	132	135	141	145	147	148
EBS-3B				121	Failed					
EAS-3C				125	127	131	135	139	148	152
EBH-3B	Dry base	None	Compound 3	135	Failed					
EAS-4B	Soil base	None	Compound 4	126	125	138	144	147	148	150
EBS-4B				137	140	143	153	163	165	158
EAS-4C				114	Failed					
EAH-4B	Dry base	None	Compound 4	121	119	Failed				
EAH-4C				129	132	136	139	142	146	151
EBH-4B				130	Failed					

Table 1-CRMA (Continued)

Specimen No.	Surface Cast on or Against	Admixture	Curing Medium	1070 Cycles 1952 %E	1155 Cycles 1953 %E	1266 Cycles 1954 %E	1411 Cycles 1955 %E	1578 Cycles 1956 %E	1722 Cycles 1957 %E	1793 Cycles (Final) 1958 %E
			Horizontally Cast Specimens (Continued)							
EBS-5B	Soil base	None	Compound 5	128	130	133	141	141	Failed	
EAS-5C				133	135	138	139	143	144	152
EAS-6B	Soil base	None	Compound 6	140	144	148	154	163	164	166
EBS-6B				71	Failed					
EAS-6C				132	134	136	138	143	147	150
EAH-6B	Dry base	None	Compound 6	162	169	178	184	191	194	201
EAH-6C				136	Failed					
EBH-6B				138	Failed					
EAS-7B	Soil base	None	Compound 7	141	Failed					
EBS-7B				117	Failed					
EAS-7C				118	124	127	129	129	134	147
EAH-7B	Dry base	None	Compound 7	157	Failed					
EAH-7C				69	Failed					
EBH-7B				149	Failed					
EAS-8B	Soil base	None	Compound 8	140	144	149	155	165	169	172
EBS-8B				138	143	151	154	154	166	169
EAS-8C				140	143	147	158	169	174	177
EAH-8B	Dry base	None	Compound 8	Failed						
EAH-8C				Failed						
EBH-8B				132	135	134	154	154	Failed	
EAS-9B	Soil base	None	Compound 9	137	141	141	150	153	154	157
EAS-9C				133	Failed					
EAH-9B	Dry base	None	Compound 9	134	Failed					
EAH-9C				140	140	139	138	138	129	111
EBH-9B				149	Failed					
EAS-10B	Soil base	None	Compound 10	140	Failed					
EBS-10B				147	147	153	157	170	171	174
EAS-10C				141	142	146	150	156	163	169
EAH-10B	Dry base	None	Compound 10	116	116	115	114	114	Failed	
EAH-10C				83	63	Failed				
EBH-10B				144	Failed					
EAS-11B	Soil base	None	Water	138	Failed					
EBS-11B				148	Failed					
EAS-11C				131	154	156	173	185	189	198
EBH-11B	Dry base	None	Water	137	Failed					
EAS-12B	Soil base	None	Air	155	161	165	172	187	190	191
EBS-12B				138	140	148	151	156	152	164
EAS-12C				159	159	168	176	192	201	206
EAH-12B	Dry base	None	Air	153	157	159	163	166	141	125
EAH-12C				175	Failed					
EBH-12B				158	160	169	172	190	187	198
EAS-13B	Soil base	B	Water	138	142	146	151	157	156	159
EBS-13B				134	136	139	143	148	146	149
EAS-13C				141	143	147	152	160	163	163
EAH-13B	Dry base	B	Water	136	138	140	141	145	145	145
EAH-13C				138	140	141	142	145	145	147
EAP-2B	Dummy specimen			---	---	---	---	---	---	---
EAS-14B	Soil base	C	Water	134	138	141	146	152	153	157
EBS-14B				143	147	152	157	166	172	177
EAS-14C				145	151	155	161	167	167	171
EAH-14B	Dry base	C	Water	139	141	145	148	152	150	153
EAH-14C				137	141	144	147	151	154	155
EBH-14B				128	131	133	135	139	142	144
EAS-15B	Soil base	D	Water	135	139	141	145	156	162	168
EBS-15B				131	131	137	142	148	142	145
EAS-15C				152	160	168	174	184	186	199
EAH-15B	Dry base	D	Water	138	140	145	151	156	163	171
EAH-15C				138	140	144	147	156	157	160
EBH-15B				133	136	137	140	148	148	153
EAS-16B	Soil base	E	Water	139	141	145	152	159	106	171
EBS-16B				131	132	137	140	149	150	153
EAS-16C				138	149	155	160	168	169	175
EAH-16B	Dry base	E	Water	132	135	137	136	139	140	140
EAH-16C				136	137	140	142	146	149	149
EBH-16B				120	122	125	127	127	134	137
EAS-17B	Soil base	F	Water	143	147	151	153	162	165	170
EBS-17B				89	135	139	142	149	150	151
EAS-17C				143	147	151	154	163	162	170

(Continued)

Table 1-CRMA (Continued) Program 7

Specimen No.	Surface Cast on or Against	Admixture	Curing Medium	1070 Cycles 1952 %E	1155 Cycles 1953 %E	1266 Cycles 1954 %E	1411 Cycles 1955 %E	1578 Cycles 1956 %E	1722 Cycles 1957 %E	1793 Cycles (Final) 1958 %E
			Horizontally Cast Specimens (Continued)							
EAH-17B	Dry base	F	Water	136	139	141	143	147	147	152
EAH-17C				141	143	147	152	155	155	131
EAR-2C	Dummy specimen			---	---	---	---	---	---	---
EAS-18B	Soil base	A	Air	159	162	169	178	189	194	205
EBS-18B			(Admixture A)	141	145	153	160	165	164	168
EAS-18C				149	152	157	164	173	183	192
EAH-18B	Dry base	A	Air	145	151	159	171	183	186	192
EAH-18C			(Admixture A)	149	153	159	169	183	191	201
EBH-18B				184	188	Failed				
EAS-19B	Soil base	Resin	Water	139	143	146	149	149	157	163
EBS-19B				136	139	142	147	147	158	243
EAS-19C				145	149	153	158	163	104	171
EAH-19B	Dry base	Resin	Water	154	156	158	183	183	128	172
EAH-19C				131	134	136	137	144	146	148
EBH-19B				130	131	133	136	141	112	114
EAS-20B	Soil base	G	Water	142	148	155	161	168	176	184
EBS-20B				165	Failed					
EAS-20C				139	145	149	153	153	101	182
EAH-20B	Dry base	G	Water	110	111	114	146	Failed		
EAH-20C				136	143	148	158	158	96	198
EBH-20B				153	Failed					
EAS-21B	Soil base	None	Special paper	147	150	152	162	175	172	190
EBS-21B				77	Failed					
EAS-21C				140	148	151	158	171	131	131
EAH-21B	Dry base	None	Special paper	169	Failed					
EBH-21B				158	Failed					
			Vertically Cast Specimens							
EAC-1B	Form lining A	None	Compound 1	128	130	127	118	118	105	Failed
EAC-1C				140	142	140	147	156	152	171
EBC-1B				118	126	Failed				
EAR-1B	Form lining B	None	Compound 1	133	136	131	133	136	130	125
EAR-1C				135	138	140	143	156	151	152
EBR-1B				113	115	112	108	110	93	138
EAP-1B	Form lining C	None	Compound 1	136	140	137	138	138	113	191
EAP-1C				135	138	144	145	152	Failed	
EBP-1B				133	137	139	140	146	144	145
EAC-2AB	Form lining A	None	Compound 2	132	137	145	146	153	159	159
EAC-2AC				135	Failed					
EBC-2B				116	114	118	107	Failed		
EAP-2AB	Form lining C	None	Compound 2	141	Failed					
EAP-2AC				138	143	Failed				
EBP-2B				144	148	151	159	162	168	184
EAR-2AB	Form lining B	None	Compound 2	113	123	128	134	136	136	146
EAR-2AC				114	113	114	110	77	95	117
EBR-2B				98	96	102	103	Failed		
EAC-3B	Form lining A	None	Compound 3	96	Failed					
EAC-3C				105	98	98	87	Failed		
EBC-3B				173	Failed					
EAR-3B	Form lining B	None	Compound 3	78	Failed					
EBR-3B				84	Failed					
EAP-3B	Form lining C	None	Compound 3	111	104	102	77	Failed		
EAP-3C				144	Failed					
EBP-3B				123	123	Failed				
EAC-4B	Form lining A	None	Compound 4	109	Failed					
EAC-4C				135	138	139	145	Failed		
EBC-4B				91	134	141	38 Fail.			
EAR-4B	Form lining B	None	Compound 4	84	77	71	52	Failed		
EAR-4C				84	79	79	73	Failed		
EBR-4B				88	118	120	160	Failed		
EAP-4B	Form lining C	None	Compound 4	103	Failed					
EAP-4C				136	136	130	117	117	117	129
EBP-4B				133	133	141	157	Failed		
EAC-5B	Form lining A	None	Compound 5	106	88	Failed				
EAC-5C				127	126	130	135	Failed		
EAR-5B	Form lining B	None	Compound 5	89	77	68	50 Fail.			
EAR-5C				Failed						

(Continued)

Specimen No.	Surface Cast on or Against	Admixture	Curing Medium	1070 Cycles 1952 %E	1155 Cycles 1953 %E	1266 Cycles 1954 %E	1411 Cycles 1955 %E	1578 Cycles 1956 %E	1722 Cycles 1957 %E	1793 Cycles (Final) 1958 %E
Vertically Cast Specimens (Continued)										
EAP-5B	Form lining C	None	Compound 5	126	119	110	110	Failed		
EAP-5C				52	Failed					
EAC-6B	Form lining A	None	Compound 6	151	158	163	172	Failed		
EAC-6C				139	139	143	150	130	136	136
EBC-6B				84	Failed					
EAR-6B	Form lining B	None	Compound 6	140	140	143	149	Failed		
EAR-6C				138	138	138	132	Failed		
EBR-6B				130	132	135	140	143	91	91
EAP-6B	Form lining C	None	Compound 6	159	159	161	158	158	158	163
EAP-6C				152	152	Failed				
EBP-6B				125	Failed					
EAC-7B	Form lining A	None	Compound 7	134	134	138	142	149	149	147
EAC-7C				133	135	139	144	150	154	154
EBC-7B				106	64	Failed				
EAR-7B	Form lining B	None	Compound 7	71	Failed					
EAR-7C				116	116	116	157	104	104	104
EBR-7B				126	126	131	138	138	102	102
EAP-7B	Form lining C	None	Compound 7	99	Failed					
EAP-7C				113	109	Failed				
EBP-7B				136	138	138	149	149	173	159
EAC-8B	Form lining A	None	Compound 8	152	152	154	190	169	169	169
EAC-8C				150	152	152	159	170	168	173
EBC-8B				146	147	151	169	166	169	166
EAR-8B	Form lining B	None	Compound 8	156	156	157	168	170	166	166
EAR-8C				146	146	148	157	164	157	156
EBR-8B				137	139	145	149	155	155	93
EAP-8B	Form lining C	None	Compound 8	174	177	179	186	189	194	186
EAP-8C				170	173	180	187	Failed		
EBP-8B				150	152	156	163	171	171	173
EAC-9B	Form lining A	None	Compound 9	121	127	130	106	Failed		
EAC-9C				130	134	156	179	Failed		
EAR-9B	Form lining B	None	Compound 9	134	138	138	146	Failed		
EAR-9C				120	120	Failed				
EBR-9B				99	74	Failed				
EAP-9B	Form lining C	None	Compound 9	156	Failed					
EAP-9C				159	Failed					
EBP-9B				146	148	152	165	118	118	118
EAC-10C	Form lining A	None	Compound 10	119	Failed					
EAR-10C	Form lining B	None	Compound 10	136	Failed					
EBR-10B				296	Failed					
EAP-10C	Form lining C	None	Compound 10	140	Failed					
EBP-10B				136	138	142	146	150	153	147
EAC-11B	Form lining A	None	Water	53	Failed					
EAC-11C				101	90	Failed				
EBC-11B				129	131	133	138	146	149	147
EAR-11C	Form lining B	None	Water	90	83	Failed				
EBR-11B				129	131	134	136	136	142	137
EAP-11C	Form lining C	None	Water	359	Failed					
EBP-11B				141	143	149	156	159	163	150
EAC-12B	Form lining A	None	Air	152	155	158	158	167	172	172
EAC-12C				152	152	154	161	168	175	166
EBC-12B				162	164	175	166	175	174	169
EAR-12B	Form lining B	None	Air	149	149	148	146	146	Failed	
EAR-12C				134	132	128	170	189	193	192
EBR-12B				152	152	155	191	125	129	129
EAP-12C	Form lining C	None	Air	99	Failed					
EBP-12B				180	180	192	198	198	209	205
EAC-13B	Form lining A	B	Water	138	136	139	143	146	148	146
EAC-13C				133	133	133	196	196	142	144
EAR-13B	Form lining B	B	Water	127	127	129	178	133	139	130
EAR-13C				134	134	136	141	143	146	146
EAP-13B	Form lining C	B	Water	138	138	140	142	142	148	140
EAP-13C				134	134	139	140	144	146	139
EAC-14B	Form lining A	C	Water	139	141	142	157	148	148	140
EAC-14C				139	139	144	146	148	150	142
EBC-14B				126	128	130	138	144	146	142

(Continued)

Specimen No.	Surface Cast on or Against	Admixture	Curing Medium	1070 Cycles 1952 %E	1155 Cycles 1953 %E	1266 Cycles 1954 %E	1411 Cycles 1955 %E	1578 Cycles 1956 %E	1722 Cycles 1957 %E	1793 Cycles (Final) 1958 %E
			Vertically Cast Specimens (Continued)							
EAR-14B	Form lining B	C	Water	132	132	136	142	143	143	145
EAR-14C				142	142	145	210	152	154	156
EBR-14B				121	123	125	131	137	138	137
EAP-14B	Form lining C	C	Water	141	141	144	148	150	153	144
EAP-14C				141	143	146	153	159	159	152
EBP-14B				121	122	125	147	135	140	138
EAC-15B	Form lining A	D	Water	130	132	134	140	143	147	142
EAC-15C				136	136	140	143	150	153	146
EBC-15B				129	129	134	140	151	151	155
EAR-15B	Form lining B	D	Water	128	130	132	138	143	144	134
EAR-15C				127	128	131	138	138	140	140
EBR-15B				125	125	129	132	95	95	95
EAP-15B	Form lining C	D	Water	139	141	144	151	157	158	160
EAP-15C				152	152	157	162	170	170	168
EBP-15B				128	130	132	139	142	146	148
EAC-16B	Form lining A	E	Water	136	136	138	140	140	147	149
EAC-16C				141	141	143	147	147	151	142
EBC-16B				122	122	124	128	130	134	134
EAR-16B	Form lining B	E	Water	136	136	137	141	141	149	147
EAR-16C				138	138	140	146	146	136	138
EBR-16B				128	130	130	137	137	140	139
EAP-16B	Form lining C	E	Water	143	145	145	150	150	152	151
EAP-16C				139	141	141	144	144	144	142
EBP-16B				126	128	130	137	142	154	152
EAC-17B	Form lining A	F	Water	142	142	143	148	151	154	154
EAC-17C				147	147	147	149	155	157	152
EAR-17B	Form lining B	F	Water	139	139	139	142	157	162	161
EAR-17C				139	137	137	139	142	141	131
EAP-17B	Form lining C	F	Water	146	147	148	149	145	151	149
EAP-17C				144	144	148	153	154	157	148
EAC-18B	Form lining A	A	Air	140	142	144	167	155	155	155
EAC-18C			(Admixture A)	144	144	144	152	156	157	150
EBC-18B				125	131	137	144	149	135	126
EAR-18B	Form lining B	A	Air	126	128	132	151	144	145	144
EAR-18C			(Admixture A)	130	134	135	140	144	147	137
EBR-18B				137	141	143	151	159	155	157
EAP-18B	Form lining C	A	Air	147	154	155	162	162	161	161
EAP-18C			(Admixture A)	154	154	156	160	168	169	165
EBP-18B				158	Failed					
EAC-19B	Form lining A	Resin	Water	134	134	135	137	140	136	138
EAC-19C				148	143	145	148	148	155	159
EBC-19B				128	128	130	131	134	140	141
EAR-19B	Form lining B	Resin	Water	135	135	136	136	143	142	142
EAR-19C				139	137	139	142	145	150	143
EBR-19B				123	121	122	124	131	126	130
EAP-19B	Form lining C	Resin	Water	147	147	149	153	157	157	149
EAP-19C				144	144	146	142	149	147	146
EBP-19B				140	140	142	145	150	154	156
EBR-20B	Form lining B	G	Water	103	106	108	121	121	125	125
EAP-20B	Form lining C	G	Water	134	135	135	148	149	144	130
EAP-20C				143	145	145	137	110	94	87

Construction Joint Program*

A general investigation of the durability of horizontal joints in mass concrete was initiated in October 1941 with the installation at Treat Island of core specimens drilled from John Martin Dam, Caddoa, Colo. The results of this initial investigation prompted the continuation of the study with three other series of concrete cores containing variously treated horizontal construction joints. The entire program involved tests of cores from the following projects:

Project	Location	No. of Cores
John Martin Dam	Caddoa, Colo.	19
Norfork Dam	Mountain Home, Ark.	4
Dale Hollow Dam	Celina, Tenn.	23
Bluestone Dam	Hinton, W. Va.	40
	Total	86

John Martin Dam

1941 installation

Nine 8-in.-diameter concrete cores drilled from the interior of the John Martin Dam and containing horizontal construction joints were installed at Treat Island in October 1941. All were exposed in the condition in which they were received, i.e. with uninsulated ends. The concrete contained type II cement, and natural sand and crushed gravel aggregates (maximum size, 6 in.). Three of the nine cores (cement factor, 3.0 bags per cu yd; water-cement ratio, 8.27 gal per bag; slump, 3/4 in.) contained horizontal construction joints cleaned with an air-water jet. Three cores (cement factor, 3.0 bags per cu yd; water-cement ratio, 8.0 gal per bag; slump, 1/2 in.) contained joints which had been subjected to no treatment. Three cores (cement factor, 3.0 bags per cu yd; water-cement ratio, 8.0 gal per bag; slump, 1/2 in.) contained joints the surfaces of which had

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* See: Corps of Engineers, Central Concrete Laboratory, John Martin Dam, Durability of Concrete Cores and Columns, Final Report (July 1942).
________, Durability of Horizontal Joints in Mass Concrete (June 1944).
________, Cores of Concrete, Dale Hollow Dam (August 1944).
________, Concrete Cores, Dale Hollow Dam (July 1945).

been cleaned by sandblasting. All nine cores deteriorated rapidly and were withdrawn for laboratory study after 120 cycles of freezing-and-thawing. Since the concrete contiguous to the joint plane had disintegrated, the precise failures of the joint planes themselves were left in doubt.

1942 installation

Ten 8-in.-diameter joint cores from John Martin Dam, representing five types of joint treatment, were installed on the exposure rack in October 1942. The ends of these cores were protected with pads of concrete containing entrained air, which were cast around each core in such manner that only 1 in. of the core on each side of the joint was exposed to weathering. The jointing material for the ten cores was cement-sand grout, and the joint surfaces had been damp-cured. Two cores represented each of five different types of joint treatment as indicated below:

No. of Joint Cores	Type of Joint Surface Treatment
2	Air-water jet plus dry-sandblast, vibrated surface
2	Air-water jet, snowshoed surface
2	Air-water jet, vibrated surface
2	Wet-sandblast, vibrated surface
2	Wet-sandblast, snowshoed surface
Total 10	

During the first winter of exposure, seven of the cores failed. One core failed after two winters, one after 19 winters, and the remaining core failed after 20 winters.

It is concluded from this exposure that:

a. The greatest degree of durability was obtained by one air-water jet, vibrated joint core which lasted 20 winters. However, one wet-sandblast, snowshoed joint core lasted 19 winters.

b. Air-water jet plus dry-sandblast, vibrated surfaces showed the poorest durability.

c. In general, surfaces compacted by snowshoeing were superior to surfaces prepared by vibration.

Table 1-CJ lists these cores, their joint-surface treatment, mixture design data, and exposure record.

Norfork Dam

Eight 8-in.-diameter joint cores were drilled from Norfork Dam. Four of these cores were untreated and four were treated. All of the untreated cores failed before they could be exposed at Treat Island. The four treated joint cores were installed at Treat Island in March 1943. The treatment consisted of hand-tamping the joint surfaces and using an air-water jet just prior to the final set of the concrete. The cores were insulated prior to installation at Treat Island with pads of concrete containing entrained air in a manner similar to the 1942 group of cores from John Martin Dam.

The concrete in the joint cores contained low-heat low-alkali cement, natural sand and gravel, and crushed limestone aggregates (maximum size, 6 in.). The cement factors were 3 and 4 bags per cu yd and the water-cement ratios were 6.19 and 8.25 gal per bag; the jointing material was a 1/2-in. layer of cement-sand grout.

All four joint cores failed during the first winter of exposure with higher-water-cement ratio lower-cement-factor cores failing before the lower-water-cement ratio higher-cement-factor cores. No significance can be attached to the failure of the joints in these four cores since there were no companion specimens with different joint treatments installed for comparison. However, the joints treated by air-water jet were stronger than untreated joints, since the joints receiving no treatment failed before they could be exposed. Table 2-CJ lists these specimens and gives their exposure record along with other pertinent information.

Dale Hollow Dam

Twenty-three 8-1/4-in.-diameter concrete cores, drilled from Dale Hollow Dam, were installed on the exposure rack at Treat Island in

December 1943. This installation was made to determine the relation of joint-surface treatment of the concrete, method of cleaning the joint areas, and the soundness of the joints as indicated by their resistance to freezing-and-thawing at Treat Island. These 23 cores represented eight types of joint treatment. Core ends were insulated with pads of air-entrained concrete in a manner similar to the 1942 group of cores from John Martin Dam. The coarse aggregate (maximum size, 6 in.) was predominantly a dark dense limestone with some oolitic limestone; a type II cement was used. Fifteen cores contained exterior concrete (cement factor, 4.5 bags per cu yd; water-cement ratio, 6.0 to 6.6 gal per bag; slump, 2-1/2 to 3 in.). Eight cores contained interior concrete (cement factor, 3.0 bags per cu yd; water-cement ratio, 8.0 gal per bag; slump, 3 in.).

All of these cores failed after being subjected to a maximum of 89 cycles of freezing-and-thawing (less than one full winter). Table 3-CJ lists these specimens and gives their exposure record along with other pertinent information.

From the standpoint of joint-surface treatment alone, the following shows the types of joint-surface treatment in order of decreasing durability:

a. Surface tamped, cut with air-water jet, and covered with a thin broomed-in layer of grout.

b. Surface tamped, cut with air-water jet, and 1/2-in. layer of grout then applied.

c. Surface tamped and a layer of grout applied as thin as could be broomed and still cover the entire surface.

d. Surface tamped and 1/2-in. layer of grout spread over the preceding lift immediately prior to placing concrete thereon.

e. Surface tamped and surface laitance removed by air-water jet.

f. Surface tamped.

g. No tamping; surface laitance removed by air-water jet applied after initial and before final set.

h. No tamping; 1/2-in. layer of grout applied after laitance removed by air-water jet.

Bluestone Dam

Forty 12-in.-diameter concrete cores, drilled from Bluestone Dam, were installed on the exposure rack at Treat Island in December 1943. Due to the difficulty encountered in locating the joints in many of the cores, they were installed with their ends uninsulated. All of the concrete from which the cores were drilled was made with type II cement containing a commercial material as a grinding aid. Twenty cores were drilled from interior concrete and twenty were drilled from exterior concrete. The interior concrete had a cement factor of 3.5 bags per cu yd and a water-cement ratio of 7.0 gal per bag. The exterior concrete had a cement factor of 4.5 bags per cu yd and a water-cement ratio of 5.5 gal per bag. The sand-aggregate ratio for both interior and exterior concrete was 32 percent. The fine aggregate was a blend of natural sand and crushed limestone; the coarse aggregate was a crushed, dark, dense limestone with some oolitic limestone (maximum size, 6 in.). The aggregate grading was poor. The joints in the cores represented ten types of joint treatment, with four cores for each type. Two of each group of four cores were drilled from interior concrete and two from exterior concrete.

All of these joint cores failed after a maximum of five winters of exposure. Only one core (exterior concrete, snowshoed surface, sandblast cleanup, and water cured) lasted for more than four winters.

The exposure record of these specimens is given in table 4-CJ along with other pertinent information.

It appears from these results that the compaction and leveling of the lift surface has a greater influence on the durability of the joint than any other factor. The leveling of surfaces by vibration appears to have a detrimental effect on the concrete immediately beneath the surface that cleanup operations cannot rectify. No clear difference was developed between the wet sandblast and the air-water jet as effective surface scourers.

(Issued Aug 1963)

Table 1-CJ

Program 8

Joint Treatment, Mixture Data, and Observations of Concrete Cores, Construction Joint Program, John Martin Dam, 1942-1962 (Installed October 1942)

Core No.	Joint Treatment: Joint Cleanup	Joint Treatment: Consolidation	Water-cement Ratio gal/bag	Cement Factor bags/cu yd	1942 Condition: 0 Cycles	1943 Condition: 91 Cycles	1943 Condition: 110 Cycles	1943 Condition: 142 Cycles	1943 Condition: 188 Cycles	1944 Condition: 319 Cycles	1944 Condition: 330 Cycles	1958 Condition: 1973 Cycles
22A-3773.03	Air-water jet	Snowshoed surface	6.45-8.21	3.0-4.0	Sound	Sound	Sound	Sound	Failed			
24A-3786.20	Air-water jet	Snowshoed surface	6.45-8.21	3.0-4.0	Sound	Sound	Sound	Sound	Sound	Failed		
22B-3776.59	Wet sandblast	Snowshoed surface	6.51-8.41	3.0-4.0	Sound	Sound	Sound	Sound	Sound	Sound	Sound	Sound
22A-3781.29	Wet sandblast	Snowshoed surface	6.51-8.41	3.0-4.0	Sound	Sound	Sound	Sound	Failed			
28A-3772.95	Air-water jet	Vibrated	6.45-7.93	3.0-4.0	Sound	Sound	Sound	Sound	Sound	Sound	Sound	Sound
28B-3786.11	Air-water jet	Vibrated	6.45-7.93	3.0-4.0	Sound		Failed					
28A-3776.44	Wet sandblast	Vibrated	6.65-8.37	3.0-4.0	Sound	Sound	Failed					
28A-3781.28	Wet sandblast	Vibrated	6.65-8.37	3.0-4.0	Sound	Sound	Sound	Failed				
24A-3771.40	Air-water jet + dry sandblast	Vibrated	7.50-8.27	3.0	Sound	Failed						
22B-3771.20	Air-water jet + dry sandblast	Vibrated	7.50-8.27	3.0	Sound	Failed						

Core No.	Joint Cleanup	Consolidation	Water-cement Ratio gal/bag	Cement Factor bags/cu yd	1959 Condition: 2123 Cycles	1960 Condition: 2194 Cycles	1961 Condition: 2335 Cycles	1962 Condition: 2424 Cycles
22B-3776.59	Wet sandblast	Snowshoed surface	6.51-8.41	3.0-4.0	Sound	Slight spalling	Failed	
28A+3772.95	Air-water jet	Vibrated	6.45-7.93	3.0-4.0	Sound	Sound	Moderate spalling	Failed

Program 8

Table 2-CJ

Joint Treatment, Mixture Data, and Observations of Concrete Cores, Construction Joint Program, Norfork Dam, 1943-1944 (Installed March 1943)

Core No.	Joint Treatment: Joint Cleanup	Joint Treatment: Curing	Joint Treatment: Cover	Consolidation	Water-cement Ratio gal/bag	Cement Factor bags/cu yd	1943 Condition: 0 Cycles	1943 Condition: 70 Cycles	1944 Condition: 75 Cycles	1944 Condition: 96 Cycles
12-394	Air-water jet	Cotton mats	1/2-in. layer sand-cement grout	Tamped	6.19	4.0	Sound	Sound	Failed	
13-394	Air-water jet	Cotton mats	1/2-in. layer sand-cement grout	Tamped	6.19	4.0	Sound	Sound	Sound	Failed
12-389	Air-water jet	Cotton mats	1/2-in. layer sand-cement grout	Tamped	6.19-8.25	3.0-4.0	Sound	Failed		
12-384	Air-water jet	Cotton mats	1/2-in. layer sand-cement grout	Tamped	8.25	3.0	Sound	Failed		

Table 3-CJ

Joint Treatment, Mixture Data, and Observations of Concrete Cores, Construction Joint Program, Dale Hollow Dam, 1943-1944 (Installed December 1943)

Core No.	Joint Treatment: Joint Cleanup	Joint Treatment: Curing	Joint Treatment: Cover	Joint Treatment: Consolidation	Water-cement Ratio gal/bag	Cement Factor bags/cu yd	1943 Condition: 0 Cycles	1943 Condition: 18 Cycles	1943 Condition: 43 Cycles	1944 Condition: 79 Cycles	1944 Condition: 89 Cycles*
5-DI-2	Air-water jet	Water	Grout	Tamped	6.0-6.2	4.5	Sound	Sound	Sound	Sound	Failed
5-E-2					6.0-6.2	4.5	Sound	Sound	Sound	Sound	Failed
30-A-1					6.0-6.2	4.5	Sound	Sound	Sound	Sound	Failed
30-B-1					6.0-6.2	4.5	Sound	Sound	Sound	Failed	
30-D-1					6.0-6.2	4.5	Sound	Sound	Sound	Failed	
30-E-1					6.0-6.2	4.5	Sound	Sound	Sound	Failed	
5-G-2					6.0-6.2	4.5	Sound	Sound	Sound	Sound	Failed
5-H-2					6.0-6.2	4.5	Sound	Sound	Sound	Sound	Failed
30-B-2					6.2-8.0	3.0-4.5	Sound	Failed			
30-X-2					6.2-8.0	3.0-4.5	Sound	Sound	Failed		
5-DI-1	None	Water	Grout	Tamped	6.0-6.8	4.5	Sound	Sound	Sound	Failed	
5-E-1					6.0-6.8	4.5	Sound	Sound	Sound	Sound	Failed
5-B-3	Air-water jet	Water	None	None	6.2-6.6	4.5	Sound	Sound	Failed		
30-D-4					8.0	3.0	Sound	Failed			
30-D-3	None	Water	None	Tamped	8.0	3.0	Sound	Failed			
30-E-3					8.0	3.0	Sound	Sound	Failed		
30-E-2	None	Water	Grout	Tamped	6.2-8.0	3.0-4.5	Sound	Failed			
5-G-1					6.0-6.8	4.5	Sound	Sound	Sound	Failed	
5-H-1					6.0-6.8	4.5	Sound	Sound	Sound	Failed	
5-B-1	Air-water jet	Water	None	Tamped	6.0-6.8	4.5	Sound	Sound	Failed		
5-C-1					6.0-6.8	4.5	Sound	Sound	Failed		
30-B-4	Air-water jet	Water	Grout	None	8.0	3.0	Sound	Failed			
30-X-4					8.0	3.0	Sound	Failed			

* All of these specimens had failed after 89 cycles of freezing-and-thawing.

(Issued Aug 1963)

Table 4-CJ

Program 8

Joint Treatment, Mixture Data, and Observations of Concrete Cores, Construction Joint Program, Bluestone Dam, 1943-1951 (Installed December 1943)

Core No.	Joint Treatment: Joint Cleanup	Joint Treatment: Curing	Joint Treatment: Cover	Joint Treatment: Consolidation	Water-cement Ratio gal/bag	Cement Factor bags/cu yd	1943 Condition 0 Cycles	1944 Condition 119 Cycles	1945 Condition 229 Cycles	1946 Condition 334 Cycles	1947 Condition 452 Cycles	1951 Condition 938 Cycles
1	Air-water jet	Water	Grout	Vibrated	5.5	4.5	Sound	Failed				
2					5.5	4.5	Sound	Failed				
5					7.0	3.5	Sound	Failed				
6					7.0	3.5	Sound	Failed				
3	Air-water jet	Sand	Grout	Vibrated	5.5	4.5	Sound	Sound	Sound	Cracking	Failed	
4					5.5	4.5	Sound	Sound	Sound*			
7					7.0	3.5	Sound	Failed				
8					7.0	3.5	Sound	Failed				
9	Air-water jet	Water	Grout	Snowshoed	5.5	4.5	Sound	Sound	Sound	Cracking	Failed	
10					5.5	4.5	Sound	Sound	Failed			
13					7.0	3.5	Sound	Failed				
14					7.0	3.5	Sound	Failed				
11	Air-water jet	Sand	Grout	Snowshoed	5.5	4.5	Sound	Failed				
12					5.5	4.5	Sound	Failed				
15					7.0	3.5	Sound	Failed				
16					7.0	3.5	Sound	Failed				
17	Wet sandblast	Water	Grout	Vibrated	5.5	4.5	Sound	Failed				
18					5.5	4.5	Sound	Failed				
21					7.0	3.5	Sound	Failed				
22					7.0	3.5	Sound	Failed				
19	Wet sandblast	Sand	Grout	Vibrated	5.5	4.5	Sound	Failed				
20					5.5	4.5	Sound	Failed				
23					7.0	3.5	Sound	Failed				
24					7.0	3.5	Sound	Failed				
25	Wet sandblast	Water	Grout	Snowshoed	5.5	4.5	Sound	Failed				
26					5.5	4.5	Sound	Sound	Sound	Sound	Sound	Failed
27					7.0	3.5	Sound	Failed				
28					7.0	3.5	Sound	Failed				
31	Wet sandblast	Sand	Grout	Snowshoed	5.5	4.5	Sound	Sound	Sound	Cracking	Failed	
32					5.5	4.5	Sound	Sound	Failed			
29					7.0	3.5	Sound	Failed				
30					7.0	3.5	Sound	Sound	Sound	Cracking	Failed	
33	None	Water	Grout	None	5.5	4.5	Sound	Failed				
34					5.5	4.5	Sound	Sound	Sound	Cracking	Failed	
37					7.0	3.5	Sound	Failed				
38					7.0	3.5	Sound	Failed				
35	None	Sand	Grout	None	5.5	4.5	Sound	Failed				
36					5.5	4.5	Sound	Sound	Sound	Cracking	Failed	
39					7.0	3.5	Sound	Sound	Cracking	Failed		
40					7.0	3.5	Sound	Failed				

* Returned to laboratory 1945.

Investigation of Finishes for Concrete Surfaces*

The purpose of this investigation was to evaluate various methods and procedures for removing unsightly surface defects from formed concrete surfaces and to establish a standard procedure for use by Corps of Engineers installations.

In June 1959, seventeen concrete panels (approximately 3-1/2 by 16-1/2 by 30 in.), with a finish mortar applied to one face of each, were installed on the Treat Island exposure rack. These panels were sawed from air-entrained concrete slabs which had the following concrete characteristics: air content, 10.0 ± 0.5%; cement factor, 5.5 bags per cu yd; slump, 2.5 ± 0.5 in. The aggregates were a manufactured limestone sand and a crushed limestone coarse aggregate (3/4-in. maximum size). The air-entraining admixture was a resin soap.

Variables under study were finishing method, grading of sand used in finish mortar, curing of concrete, age of concrete before mortar was applied, etc.

Seventeen companion panels were installed out-of-doors at Jackson, Miss., for control purposes.

Table 1-F lists the Treat Island panels, and gives their exposure record along with other data pertinent to the finishing.

The exposure of these specimens was terminated in August 1962 after three winters and a final report* of this investigation was issued. The conclusions drawn from these exposures were:

a. Effect of mortar sand grading: No appreciable differences were noted in the four test panels exposed at either exposure station.

b. Effect of mortar sand-cement ratio: The Treat Island panels exhibited no appreciable differences. A comparison of the panels exposed to weathering at Jackson showed the panels finished with a mortar consisting of 1 part cement to 2 parts sand by volume, applied either by the Portland Cement Association or Bureau of Reclamation method, to be more durable than the panels finished with a mortar of 1 part cement to 1-1/2 parts sand.

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* See U. S. Army Engineer Waterways Experiment Station, CE, Investigation of Methods of Finishing Formed Concrete Surfaces, Technical Report No. 6-559 (Vicksburg, Miss., December 1960).

c. Effect of mortar-application method: The Treat Island panels exhibited no appreciable differences. The panels exposed to weathering at Jackson appeared to indicate that sack rubbing provides a concrete finish that is tight, inconspicuous, and smoother than that provided by sponging.

d. Effect of age of concrete at time of finish: No significant differences were apparent in the panels exposed at either location.

e. Effect of curing after finishing: No significant differences were apparent in the panels exposed at either location.

f. Effect of exposure conditions at time of finishing: No significant differences were apparent in the panels exposed at either location.

(Revised Aug 1963)

Table 1-F

Program 9

Observations of Mortar-finished Concrete Panels, Investigation of Finishes for Concrete Surfaces

1959-1962 (Installed June 1959)

Panel No.	Concrete Curing Before Finishing: No. Days Water-cured	No. Days Dried	Curing Location	Age at Time of Finishing days	Finishing Method	Finish Applied by	Finish Mortar: Cement-sand Ratio by wt	Cement-sand Ratio by vol	Sieve Size Sand Used	Curing Method and Days	Condition of Panels 1959-: 1959	1960	1961	1962
Being Tested for Effects of Mortar Sand Grading														
1	7	21	Indoors	28	PCA*	Sack rubbing	1:1.5		-30	None	Sound	Spalling	Spalling	Spalling
2		21	Indoors	28	PCA mod**	Sack rubbing	1:1.5		-16	None	Sound	Sound	Sound	Spalling
3	2		Indoors	2	BR†	Sack rubbing		1:2	-16	Water-cured, 5	Sound	Sl sp††	Sl sp	Spalling
4	2		Indoors	2	BR mod‡	Sack rubbing		1:2	-30	Water-cured, 5	Sound	Sound	Sound	Sl sp
Being Tested for Effects of Mortar Sand-cement Ratio														
5	7	21	Indoors	28	PCA mod	Sack rubbing	1:2		-30	None	Sound	Sound	Sl sp	Spalling
6	2		Indoors	2	BR mod	Sack rubbing		1:1.5	-16	Water-cured, 5	Sound	Sound	Sound	Spalling
Being Tested for Effects of Mortar-application Method														
7	7	21	Indoors	28	PCA mod	Sponging	1:1.5		-30	None	Sound	Sl sp	Sl sp	Spalling
8	2		Indoors	2	BR mod	Sponging		1:2	-16	Water-cured, 5	Sound	Sl sp	Sl sp	Sl sp
Being Tested for Effects of Age of Concrete at Time of Finish														
9	1		Indoors	1	BR mod	Sack rubbing		1:2	-16	Water-cured, 5	Sound	Sound	Sound	Sl sp
10	3		Indoors	3	BR mod	Sack rubbing		1:2	-16	Water-cured, 5	Sound	Sl sp	Sl sp	Sl sp
11	7	83	Indoors	90	BR mod	Sack rubbing		1:2	-16	Water-cured, 5	Sound	Sound	Sound	Sl sp
12	2		Indoors	2	PCA mod	Sack rubbing	1:1.5		-30	None	Sound	Sound	Sound	Spalling
13	7	83	Indoors	90	PCA mod	Sack rubbing	1:1.5		-30	None	Sound	Sound	Sound	Sl sp
Being Tested for Effects of Curing After Finishing														
14	7	21	Indoors	28	PCA mod	Sack rubbing	1:1.5		-30	Water-cured, 5	Sound	Sound	Sound	Sl sp
15	2		Indoors	2	BR mod	Sack rubbing		1:2	-16	None	Sound	Sound	Sound	Sound
Being Tested for Effects of Exposure Conditions at Time of Finishing														
16	7	21	Outdoors	28	PCA mod	Sack rubbing	1:1.5		-30	Water-cured, 5	Sound	Sound	Sound	Spalling
17	2		Outdoors	2	BR mod	Sack rubbing		1:2	-16	None	Sound	Hy sp‡‡	Hy sp	Hy sp

* Method used by Portland Cement Association.
** Method used by Portland Cement Association modified.
† Method used by Bureau of Reclamation.
†† Sl sp denotes slight spalling.
‡ Method used by Bureau of Reclamation modified.
‡‡ Hy sp denotes heavy spalling.

National Bureau of Standards Program*

In October 1943, 116 concrete columns** (6 by 6 by 48 in.) were installed on the Treat Island exposure rack as a part of the National Bureau of Standards test program to determine the influence of admixture A on the durability of concrete.

The specimens (which were manufactured by the National Bureau of Standards) represented 13 cements, which were used in each of the following three types of concrete:

Mix No.	Admixture	Slump in.	Cement Factor bags/cu yd	Water-cement Ratio by Weight
1	None	3-1/2	5.95 ± 0.10	0.537
2	A	3-1/2	5.95 ± 0.10	0.467
3	A	6	5.95 ± 0.10	0.494

Admixture A was added to the cement in the amount of one pound per bag of cement. The aggregates used consisted of natural sand and siliceous gravel.

Table 1-NBS lists these specimens and gives their exposure record along with other pertinent information.

This exposure was discontinued in 1967 after 115 of the test specimens had failed. The one remaining specimen (M-6-1) had undergone 2926 cycles of freezing-and-thawing in 24 winters at Treat Island. Final determinations of %E were made on specimen M-6-1 in 1966 after 2770 cycles of freezing-and-thawing (23 winters).

Over 50 percent of the test columns (67 specimens) failed during the first four winters, with 26 of these failing the first winter, 20 the second winter, 17 the third winter, and only 4 the fourth winter.

The findings of this investigation were:

a. With cements B, C, J, L, M, and N the concrete columns made from mixture 3 had greater durability than the columns made from mixture 2.

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* See National Bureau of Standards Interim Reports to the Office, Chief of Engineers (December 1943, July 1944).

** Columns are molded with the long axis in a vertical position.

b. With cements A, D, E, F, G, and H, mixtures 2 and 3 had essentially equal durability.

c. With cement K, mixture 2 had greater durability than mixture 3.

d. With all cements except cement H, columns made from mixture 3 exhibited greater durability than did the columns made from mixture 1.

e. With all cements except cement H, columns made from mixture 2 had greater durability than columns made from mixture 1. As mixture 2 contained admixture A and mixture 1 did not, it appears that the use of admixture A increased the durability of the concrete with all cements except cement H, which was the only type III cement in this program. This indicates that the effectiveness of admixture A is dependent upon the brand of cement used with it and cannot be regarded as being effective with all cements.

f. Column M-6-1, the only specimen remaining after 24 winters at Treat Island, was made from mixture 3 using a low-heat cement.

(Issued Sept 1967)

Table 1-NBS

Program 10

Record of Observations and Testing of Concrete Columns Containing Admixture A, National Bureau of Standards Program, 1943- (Installed October 1943)

Spec No.	Cement Type and Designation*	Admixture	Nominal Slump in.	1943-1952 Observations: 0 Cycles 1943 %E	143 Cycles 1944 %E	252 Cycles 1945 %E	357 Cycles 1946 %E	475 Cycles 1947 %E	606 Cycles 1948 %E	711 Cycles 1949 %E	872 Cycles 1950 %E	961 Cycles 1951 %E	1062 Cycles 1952 %E
A-1	I, A	None	3-1/2	100	111	112	77	35 Fail.					
A-2				100	99	Fail.							
A-3				100	110	Fail.							
A-3-1	I, A	A	3-1/2	100	106	114	114	117	66	57	Fail.		
A-3-2				100	106	111	119	123	95	84	70	69	63
A-3-3				100	106	114	120	108	90	72	59	58	54
A-6-1	I, A	A	6	100	107	117	119	117	94	50 Fail.			
A-6-2				100	108	117	121	125	114	103	91	86	77
A-6-3				100	108	116	119	125	113	96	89	90	114
B-1	I, B	None	3-1/2	100	Fail.								
B-2				100	Fail.								
B-3				100	Fail.								
B-3-1	I, B	A	3-1/2	100	116	74	50 Fail.						
B-3-2				100	115	Fail.							
B-3-3				100	119	Fail.							
B-6-1	I, B	A	6	100	122	121	124	33 Fail.					
B-6-2				100	111	Fail.							
B-6-3				100	119	Fail.							
C-1	II, C	None	3-1/2	100	Fail.								
C-2				100	Fail.								
C-3				100	Fail.								
C-3-1	II, C	A	3-1/2	100	108	Fail.							
C-3-2				100	106	Fail.							
C-3-3				100	Fail.								
C-6-1	II, C	A	6	100	110	Fail.							
C-6-2				100	108	Fail.							
C-6-3				100	114	123	83	73	69	50 Fail.			
D-1	II, D	None	3-1/2	100	120	126	76	50 Fail.					
D-2				100	107	113	48 Fail.						
D-3				100	118	128	84	50 Fail.					
D-3-1	II, D	A	3-1/2	100	110	118	122	130	119	107	70	78	50 Fail.
D-3-2				100	108	116	120	112	76	46 Fail.			
D-3-3				100	111	119	123	130	124	118	106	104	94
D-6-1	II, D	A	6	100	112	123	128	132	125	120	82	69	65
D-6-2				100	106	116	110	89	34 Fail.				
D-6-3				100	113	123	126	131	117	109	97	96	90
E-1	II, E	None	3-1/2	100	Fail.								
E-2				100	Fail.								
E-3				100	113	115	50 Fail.						
E-3-1	II, E	A	3-1/2	100	109	116	103	56	50 Fail.				
E-3-2				100	110	118	103	70	55	50 Fail.			
E-3-3				100	111	120	86	85	75	50 Fail.			
E-6-1	II, E	A	6	100	112	120	120	90	68	50 Fail.			
E-6-2				100	112	121	123	110	72	50 Fail.			
E-6-3				100	114	120	30 Fail.						
F-1	II, F	None	3-1/2	100	Fail.								
F-2				100	Fail.								
F-3				100	Fail.								
F-3-1	II, F	A	3-1/2	100	110	120	122	128	101	83	80	66	--
F-3-2				100	110	119	88	83	83	46 Fail.			
F-3-3				100	109	118	85	88	62	50 Fail.			
F-6-1	II, F	A	6	100	111	121	124	126	78	61	59	Fail.	
F-6-2				100	112	122	124	124	91	81	93	108	108
F-6-3				100	109	119	69	64	64	45 Fail.			
G-1	II, G	None	3-1/2	100	Fail.								
G-2				100	Fail.								
G-3				100	Fail.								

(Continued)

* The 13 cements used are designated A through H and J through N.

(Issued Sept 1967)

Program 10

Table 1-NBS (Continued)

Spec No.	Cement Type and Destination	Admixture	Nominal Slump in.	1943-1952 Observations: 0 Cycles 1943 %E	143 Cycles 1944 %E	252 Cycles 1945 %E	357 Cycles 1946 %E	475 Cycles 1947 %E	606 Cycles 1948 %E	711 Cycles 1949 %E	872 Cycles 1950 %E	961 Cycles 1951 %E	1062 Cycles 1952 %E
G-3-1	II, G	A	3-1/2	100	109	118	49 Fail.						
G-3-2				100	112	121	49 Fail.						
G-3-3				100	109	96	49 Fail.						
G-6-1	II, G	A	6	100	112	119	49 Fail.						
G-6-2				100	117	119	50 Fail.						
G-6-3				100	113	Fail.							
H-1	III, H	None	3-1/2	100	115	115	116	113	50 Fail.				
H-2				100	110	121	123	115	80	45 Fail.			
H-3				100	110	122	103	81	81	46 Fail.			
H-3-2	III, H	A	3-1/2	100	105	109	41 Fail.						
H-3-3				100	94	Fail.							
H-6-1	III, H	A	6	100	108	119	43 Fail.						
H-6-2				100	107	118	43 Fail.						
H-6-3				100	107	118	43 Fail.						
I-1	I, J	None	3-1/2	100	81	Fail.							
I-2				100	Fail.								
I-3				100	115	121	49 Fail.						
I-3-1	I, J	A	3-1/2	100	108	117	116	119	100	50 Fail.			
I-3-2				100	110	115	116	121	50 Fail.				
I-3-3				100	109	114	78	82	51	50 Fail.			
I-6-1	I, J	A	6	100	108	111	108	80	Fail.				
1-6-2				100	114	116	117	119	Fail.				
I-6-3				100	109	113	110	101	88	83	79	76	78
J-1	II, K	None	3-1/2	100	Fail.								
J-2				100	116	120	35 Fail.						
J-3				100	Fail.								
J-3-1	II, K	A	3-1/2	100	107	120	123	129	120	117	110	114	114
J-3-2				100	110	121	123	125	112	106	103	109	110
J-3-3				100	109	120	123	130	121	118	117	119	121
J-6-1	II, K	A	6	100	114	124	127	133	123	117	108	110	113
J-6-2				100	112	126	126	132	123	120	118	120	121
J-6-3				100	111	123	125	129	118	115	109	113	117
K-1	I, L	None	3-1/2	100	Fail.								
K-2				100	109	Fail.							
K-3				100	Fail.								
K-3-1	I, L	A	3-1/2	100	110	122	66	64	Fail.				
K-3-2				100	110	Fail.							
K-3-3				100	108	118	76	75	61	46 Fail.			
K-6-1	I, L	A	6	100	115	126	111	112	106	106	103	111	112
K-6-2				100	114	99	69	[illegible]	55	46 Fail.			
K-6-3				100	109	111	90	87	80	81	61	62	53
L-1	II, M	None	3-1/2	100	Fail.								
L-2				100	Fail.								
L-3				100	Fail.								
L-3-1	II, M	A	3-1/2	100	116	Fail.							
L-3-2				100	112	Fail.							
L-3-3				100	109	104	102	112	50 Fail.				
L-6-1	II, M	A	6	100	121	Fail.							
L-6-2				100	111	Fail.							
L-6-3				100	109	111	108	110	126	98	102	107	Fail.
M-1	LH,** N	None	3-1/2	100	Fail.								
M-2				100	Fail.								
M-3				100	Fail.								
M-3-1	LH, N	A	6	100	118	Fail.							
M-3-2				100	115	121	35 Fail.						
M-3-3				100	112	116	109	144	140	142	144	146	50 Fail.
M-6-1	LH, N	A	6	100	121	129	133	142	138	133	121	123	126
M-6-2				100	123	129	49 Fail.						
M-6-3				100	115	125	131	141	139	134	50 Fail.		

(Continued)

** LH denotes low heat.

Table 1-NBS (Concluded)

Spec No.	Cement Type and Designation	Admixture	Nominal Slump in.	1953-1959 Observations: 1147 Cycles 1953 Condition or %E	1147 Cycles 1953 Pulse Veloc fps	1147 Cycles 1953 $\%V^2$	1258 Cycles 1954 %E	1258 Cycles 1954 $\%V^2$	1403 Cycles 1955 Condition or %E	1403 Cycles 1955 $\%V^2$	1570 Cycles 1956 %E	1570 Cycles 1956 $\%V^2$	1714 Cycles 1957 %E	1714 Cycles 1957 $\%V^2$	1785 Cycles 1958 %E	1785 Cycles 1958 $\%V^2$	1935 Cycles 1959 %E	1935 Cycles 1959 $\%V^2$
A-3-2	I, A	A	3-1/2	Failed														
A-3-3				Failed														
A-6-2	I, A	A	6	Failed														
A-6-3				Failed														
D-3-3	II, D	A	3-1/2	Failed														
D-6-1	II, D	A	6	Failed														
D-6-3				Failed														
F-3-1	II, F	A	3-1/2	Failed														
F-6-2	II, F	A	6	Failed														
I-6-3	I, J	A	6	74	--	--	69	--	Failed									
J-3-1	II, K	A	3-1/2	124	14,925	100	121	98	120	100	123	99	120	--	123	--	117	--
J-3-2				115	14,495	100	114	99	115	--	121	--	123	--	149	--	133	--
J-3-3				128	14,705	100	133	100	133	--	140	--	137	--	137	--	131	--
J-6-1	II, K	A	6	115	14,925	100	122	96	120	100	123	96	113	96	107	97	104	--
J-6-2				128	14,870	100	127	99	125	99	129	99	119	95	122	93	116	--
J-6-3				129	--	--	134	--	139	--	137	--	140	--	143	--	140	--
K-6-1	I, L	A	6	Failed														
K-6-3				Failed														
M-6-1	LH**, N	A	6	134	14,390	100	137	98	150	94	158	--	166	--	194	--	182	--

Spec No.	Cement Type and Designation	Admixture	Nominal Slump in.	1960-1966 Observations: 2006 Cycles 1960 %E	2006 Cycles 1960 $\%V^2$	2147 Cycles 1961 %E	2147 Cycles 1961 $\%V^2$	2236 Cycles 1962 %E	2236 Cycles 1962 $\%V^2$	2342 Cycles 1963 %E	2342 Cycles 1963 $\%V^2$	2477 Cycles 1964 %E	2477 Cycles 1964 $\%V^2$	2640 Cycles 1965 %E	2640 Cycles 1965 $\%V^2$	2770†† Cycles 1966 %E	2770†† Cycles 1966 $\%V^2$
J-3-1	II, K	A	3-1/2	111	--	117	--	Failed									
J-3-2				120	--	120	--	NR†	--	Failed							
J-3-3				125	--	125	--	116	--	99	--	80	--	Failed			
J-6-1	II, K	A	6	82	--	Failed											
J-6-2				Failed													
J-6-3				127	--	127	--	Failed									
M-6-1	LH**, N	A	6	182	--	190	--	186	--	182	--	174	--	170	--	186	--

** LH denotes low heat.
† NR denotes a satisfactory reading was not obtained.
†† Final reading.

Rome Air Depot Program*

The purpose of this investigation was to determine the durability of concrete used at Rome Air Depot, N. Y., by exposure of both cast and sawed concrete beams.

Cast Beams

In December 1941, 15 concrete beams (6 by 6 by 48 in.) were installed on the exposure rack at Treat Island. The beams were prepared at the project and represented job concrete made with the following cements:

a. Plain portland cement (3 beams)

b. Plain portland cement plus natural cement with interground tallow, ratio 6:1 (3 beams)

c. Portland cement with interground resin (6 beams)

d. Portland cement with interground resin plus natural cement with interground tallow, ratio 6:1 (3 beams)

The nominal cement factor was 6.0 bags per cu yd and the nominal water-cement ratio was 4.5 gal per bag.

Table 1-ADB lists these specimens and gives their exposure record.

This exposure was terminated in 1967 after 26 winters of exposure (3254 cycles of freezing-and-thawing) as the test specimens were no longer yielding useful data. Final determinations of %E and $\%V^2$ were made in 1966 on the 10 remaining specimens after 3098 cycles of freezing and thawing (25 winters).

The ten specimens remaining at the time of termination of the

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* See: Central Concrete Laboratory, Cement Durability Program, First Interim Report (June 1942).

__________, Concrete Research, Second Interim Report, Part I, "Laboratory Studies of Concrete Containing Air-entraining Admixtures" (July 1945).

__________, Surface Scaling of Concrete Runways - Rome Air Depot (October 1943).

program represented three of the four test conditions. The three beams made with plain portland cement (mix a, above), i.e. without an air-entraining agent, failed after one winter of exposure. All six beams made with a portland cement containing interground resin (mix c) survived the 26 winters. The three beams made with plain portland cement plus natural cement with interground tallow (mix b) also survived the exposure. Only one of the three beams made with portland cement with interground resin plus natural cement with interground tallow (mix d) survived.

Sawed Beams

In October 1943, three concrete beams (5-1/2 by 6 by 30 in.) sawed from a slab extracted from the E-W runway were installed on the Treat Island exposure rack. They contained cement interground with resin (water-cement ratio, 5.0 gal per bag; cement factor, 6.0 bags per cu yd) and 6-in.-mesh, No. 6 wire reinforcement approximately 2 in. from the top surface of the concrete as cast. These specimens showed slight scaling at the time of their extraction. The purpose of this installation was to determine whether further scaling would develop as a result of severe weathering. However, these beams were lost overboard in a storm in March 1955.

The appearance of the beams when last inspected (15 March 1955) before they were lost was as follows:

Beam No.	Appearance 15 March 1955
S-1-J	Moderate spalling
S-1-I	Slight scaling and spalling
S-1-H	Slight scaling and heavy spalling

Table 2-ADB lists the specimens and gives their exposure record.

Since this exposure was terminated prematurely because of loss of the specimens, meaningful conclusions cannot be drawn in regard to the sawed beams.

Findings

Cast beams

The order of durability of the four concrete mixtures tested was as follows (most durable to least durable):

(1) Plain portland cement plus natural cement with interground tallow.
Portland cement with interground resin.

(2) Portland cement with interground resin plus natural cement with interground tallow.

(3) Plain portland cement.

(Issued Sept 1967)

Table 1-ADB — Program 11

Record of Testing of Cast Concrete Beams, Rome Air Depot Program

1941-1966 (Installed December 1941)

Specimen No.	Cement	1941-1952 Readings											
		0 Cycles 1941 %E	140 Cycles 1942 %E	328 Cycles 1943 %E	470 Cycles 1944 %E	580 Cycles 1945 %E	685 Cycles 1946 %E	803 Cycles 1947 %E	934 Cycles 1948 %E	1039 Cycles 1949 %E	1200 Cycles 1950 %E	1289 Cycles 1951 %E	1390 Cycles 1952 %E
ADB-P-2	Plain portland	100	Failed										
ADB-P-4		100	Failed										
ADB-P-6		100	Failed										
ADB-N-2	Portland +	100	104	107	108	116	114	124	111	108	106	107	107
ADB-N-4	nat	100	103	106	108	116	115	123	100	96	96	98	97
ADB-N-6	w/tallow	100	105	105	107	116	117	122	111	108	109	107	108
ADB-V-2	Portland w/resin	100	102	106	107	114	118	123	113	111	112	115	114
ADB-V-4		100	102	106	109	116	119	125	115	112	114	116	117
ADB-V-6		100	102	107	109	116	118	124	112	110	110	112	112
ADB-VV-2	Portland w/resin	100	102	107	109	113	115	123	115	112	115	118	119
ADB-VV-4		100	103	107	109	116	119	125	115	112	114	116	118
ADB-VV-6		100	103	108	110	117	120	126	115	114	118	121	121
ADB-VN-2	Portland w/resin	100	103	103	104	112	114	122	107	105	106	107	108
ADB-VN-4	+ nat	100	102	103	104	111	113	121	105	103	102	100	--
ADB-VN-6	w/tallow	100	100	103	105	113	114	122	106	102	102	101	101

Specimen No.	Cement	1953-1960 Readings																	
		1475 Cycles 1953			1586 Cycles 1954		1731 Cycles 1955		1898 Cycles 1956		2042 Cycles 1957		2113 Cycles 1958		2263 Cycles 1959		2334 Cycles 1960	
		%E	Pulse Veloc fps	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$
ADB-N-2	Portland +	112	16,950	100	116	96	120	99	118	97	109	92	112	97	109	88	106	91
ADB-N-4	nat	104	16,530	100	109	96	111	102	113	98	96	93	106	97	101	89	91	94
ADB-N-6	w/tallow	112	16,600	100	115	109	119	103	116	99	107	94	112	100	107	92	107	94
ADB-V-2	Portland w/resin	120	17,095	100	121	98	125	100	119	97	117	94	120	97	115	90	112	91
ADB-V-4		121	17,240	100	124	98	129	101	122	97	116	94	119	96	114	91	111	93
ADB-V-6		112	17,165	100	117	98	122	99	117	96	108	88	111	94	108	83	103	93
ADB-VV-2	Portland w/resin	123	17,545	100	127	101	132	102	127	97	112	95	122	102	117	91	117	94
ADB-VV-4		122	17,240	100	126	102	131	103	126	97	112	93	122	100	117	93	117	94
ADB-VV-6		126	17,545	100	129	97	130	98	130	94	118	92	126	95	121	88	118	91
ADB-VN-2	Portland w/resin	111	16,735	100	114	98	117	99	114	97	106	92	106	98	101	88	98	92
ADB-VN-4	+ nat	94	16,460	100	86	92	77	94	62	85	79	59	71	63	Fail			
ADB-VN-6	w/tallow	104	16,665	100	103	95	103	98	99	90	104	85	99	91	86	82	81	82

Specimen No.	Cement	1961-1966 Readings											
		2475 Cycles 1961		2564 Cycles 1962		2670 Cycles 1963		2805 Cycles 1964		2968 Cycles 1965		3098* Cycles 1966	
		%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$
ADB-N-2	Portland +	114	92	106	95	106	105	95	65	95	78	88	78
ADB-N-4	nat	98	93	91	95	86	98	77	88	75	--	84	--
ADB-N-6	w/tallow	110	92	107	86	104	101	99	87	97	75	107	77
ADB-V-2	Portland w/resin	115	90	110	90	110	99	105	88	102	75	102	76
ADB-V-4		116	90	111	91	106	93	103	88	100	75	102	81
ADB-V-6		105	89	103	53	101	100	91	83	91	72	91	72
ADB-VV-2	Portland w/resin	117	95	112	98	112	98	110	90	105	74	103	90
ADB-VV-4		117	93	114	91	110	100	108	90	106	74	106	83
ADB-VV-6		121	89	116	92	113	90	110	86	110	73	105	81
ADB-VN-2	Portland w/resin	98	89	93	97	91	97	89	84	87	76	99	71
ADB-VN-4	+ nat												
ADB-VN-6	w/tallow	76	80	72	47	70	73	57	70	57	76	Failed	

* Final reading.

(Issued Sept 1967)

Program 11

Table 2-ADB

Record of Testing of Sawed Concrete Beams, Rome Air Depot Program

1943-1954 (Installed October 1943)

		1943-1954 Readings														
		0 Cycles 1943	142 Cycles 1944	252 Cycles 1945	357 Cycles 1946	475 Cycles 1947	606 Cycles 1948	711 Cycles 1949	812 Cycles 1950	961 Cycles 1951	1062 Cycles 1952	1147 Cycles 1953			1258* Cycles 1954	
Specimen	Cement	%E	%E	%E	%E	%E	%E	%E	%E	%E	%E	%E	Pulse Veloc fps	$\%V^2$	%E	$\%V^2$
S-1-H	Portland w/resin	100	100	100	106	--	100	100	100	101	106	107	17,125	100	108	99
S-1-I		100	100	101	101	--	99	99	98	99	98	99	17,125	100	100	93
S-1-J		100	100	101	106	--	100	100	99	100	102	104	17,005	100	105	96

Note: All three specimens lost overboard in storm in March 1955.
* Final reading.

Syracuse Air Base Beams

In October 1942, 18 concrete beams (6 by 6 by 48 in.) were installed on the exposure rack at Treat Island. The concrete used in these beams was extracted from regular field batches used in the runway pavement at the Syracuse Air Base, N. Y. The specimens were prepared at the project and were cured by the use of a black membrane curing compound. The purpose of this installation was to determine the durability of concrete containing a resin used at Syracuse Air Base.

Six of the 18 specimens were made from a mixture containing type I plain portland cement; six were made from a mixture containing type II portland cement with interground resin; and six were made from a mixture containing type I portland cement to which 0.02% resin soap had been added at the mixer.

Table 1-SY lists these specimens and gives their exposure record along with mixture data.

This exposure was terminated in 1967 after 25 winters of exposure (3114 cycles of freezing-and-thawing) as the test specimens were no longer yielding useful data. Final determinations of %E were made in 1966 after 2958 cycles of freezing-and-thawing (24 winters).

Only four specimens* remained under exposure at the time of termination; all of these were made with a type II portland cement with interground resin. The six beams made with a plain type I portland cement all failed after one winter of exposure. Two beams made with the type I cement and resin soap also failed; the remaining four beams were removed from the exposure rack prior to 1966.

Findings

The order of durability of the three concrete mixtures tested was

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* Only one of the beams in this group failed during the exposure. Also one beam was discarded in 1943 to make room for other specimens.

as follows (most durable to least durable):

(1) Type II portland cement with interground resin.

(2) Type I portland cement with resin soap.

(3) Type I portland cement (plain).

(Issued Sept 1967)

Table 1-SY

Program 12

Mixture Data and Record of Testing of Syracuse Air Base Beams

1942-1966 (Installed October 1942)

Beam No.	Type Cement	Water Cement Ratio gal/bag	Cement Factor bags/cu yd	1942-1951 Readings 0 Cycles 1942 %E	188 Cycles 1943 %E	330 Cycles 1944 %E	440 Cycles 1945 %E	545 Cycles 1946 %E	663 Cycles 1947 %E	794 Cycles 1948 %E	899 Cycles 1949 %E	1060 Cycles 1950 %E	1149 Cycles 1951 %E
SYO-117A	II, A	6.0	5.5	100	108	108	114	118	122	115	113	112	114
SYO-117B	w/inter-			100	107	114	117	130	139	128	130	132	133
SYO-117C	ground			100	Sound, discarded to make room for additional specimens, Aug 1943								
SYO-117D	resin			100	106	110	114	107	112	111	105	105	107
SYO-117E				100	106	110	118	131	141	120	136	134	137
SYO-117F				100	105	108	116	118	122	109	115	115	117
SYH-136A	I, B	6.5	5.3	100	F								
SYH-136B	plain			100	F								
SYH-136C				100	F								
SYH-136D				100	F								
SYH-136E				100	F								
SYH-136F				100	F								
SYH-137A	I, B	6.0	5.3	100	Sound, discarded to make room for additional specimens, Aug 1943								
SYH-137B	w/resin			100	105	95	102	103	106	90	95	92	92
SYH-137C	soap			100	Sound, discarded to make room for additional specimens, Aug 1943								
SYH-137D				100	Sound, discarded to make room for additional specimens, Aug 1943								
SYH-137E				100	105	105	121	128	134	108	123	115	117
SYH-137F				100	94	96	103	101	107	107	107	95	95

Beam No.	Type Cement	Water Cement Ratio gal/bag	Cement Factor bags/cu yd	1952-1958 Readings 1250 Cycles 1952 %E	1335 Cycles, 1953 %E	1335 Cycles, 1953 Pulse Veloc fps	1335 Cycles, 1953 $\%V^2$	1446 Cycles 1954 %E	1446 Cycles 1954 $\%V^2$	1591 Cycles 1955 %E	1591 Cycles 1955 $\%V^2$	1758 Cycles 1956 %E	1758 Cycles 1956 $\%V^2$	1902 Cycles 1957 %E	1902 Cycles 1957 $\%V^2$	1973 Cycles 1958 %E	1973 Cycles 1958 $\%V^2$
SYO-117A	II, A	6.0	5.5	113	115	16,950	100	117	91	116	89	118	87	113	86	134	85
SYO-117B	w/inter-			134	139	13,840	100	144	100	144	98	144	94	139	92	146	95
SYO-117D	ground			109	111	13,890	100	116	98	116	97	115	97	120	90	114	92
SYO-117E	resin			138	141	13,650	100	147	102	148	99	147	101	118	95	125	96
SYO-117F				120	122	13,700	100	129	101	129	99	128	93	Broken, 1956			
SYH-137B	I, B	6.0	5.3	91	92	14,135	100	87	93	89	88	87	90	87	--	93	--
SYH-137E	w/resin			115	115	11,835	100	114	--	103	--	103	--	72	--	63	--
SYH-137F	soap			94	95	13,745	100	71	97	90	--	90	90	90	--	Broken '58	

Beam No.	Type Cement	Water Cement Ratio gal/bag	Cement Factor bags/cu yd	1959-1966 Readings 2123 Cycles 1959 %E	2123 Cycles 1959 $\%V^2$	2194 Cycles 1960 %E	2194 Cycles 1960 $\%V^2$	2335 Cycles 1961 %E	2335 Cycles 1961 $\%V^2$	2424 Cycles 1962 %E	2424 Cycles 1962 $\%V^2$	2530 Cycles 1963 %E	2530 Cycles 1963 $\%V^2$	2665 Cycles 1964 %E	2665 Cycles 1964 $\%V^2$	2828 Cycles 1965 %E	2828 Cycles 1965 $\%V^2$	2958** Cycles 1966 %E	2958** Cycles 1966 $\%V^2$
SYO-117A	II, A	6.0	5.5	105	79	108	83	100	82	92	31	80	82	90	--	98	--	103	--
SYO-117B	w/inter-			124	89	117	91	117	86	110	34	100	89	88	--	91	--	109	--
SYO-117D	ground			102	88	96	89	96	--	88	--	80	--	75	--	80	--	102	--
SYO-117E	resin			132	90	125	91	128	91	108	88	102	81	90	--	96	--	125	--
SYH-137B	I, B	6.0	5.3	67	--	F*													
SYH-137E	w/resin soap			61	--	F													

* F denotes specimen has failed.

** Final reading.

Natural Cement Investigation*

The purpose of this investigation was to study the relative durability of concrete containing blends of natural with portland cement as compared to (a) similar concrete containing plain portland cement, and (b) concrete containing air purposefully entrained through the use of resin.

In October 1942, 94 concrete columns** (6 by 6 by 48 in.) were installed on the Treat Island exposure rack as a part of this program. The aggregates were a natural siliceous sand and crushed traprock of 3/4-in. maximum size. The cements used were: three plain portland cements, the same portland cements with a neutralized resin added to the mixing water, 15 blends of three plain portland cements with five natural cements; and 10 blends of one natural cement (interground with four different percentages of resin) with two portland cements. All of the natural cements contained some form of air-entraining agent except natural cement D. All blends were proportioned in the ratio of 1 bag of natural cement to 5 bags of portland cement (1:5.875 by weight) and a water-cement ratio of 6 gal per bag.

Table 1-CRN lists these specimens and gives their exposure record along with their cement factors.

This exposure was terminated in 1967 after 3114 cycles of freezing-and-thawing (25 winters) with 54 specimens remaining. The final determinations of %E and %V^2 were made in 1966 after 24 winters of exposure (2958 cycles of freezing-and-thawing). A summary of the test variables and number of columns remaining per variable is shown in the following tabulation:

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* See Central Concrete Laboratory, Tests of Blends of Portland and Natural Cements (June 1944).

** Columns are fabricated with their long axis in a vertical position.

Program 13 (Issued Sept 1967)

Test Condition	Cements Used	Portland Cement	Natural Cement	Neutralized or Interground Resin	No. of Columns Installed	No. of Columns Remaining in 1967
1	Portland cement only	Type II, A	None	None	3	0
		Type I, B	None	None	3	0*
		Type II, C	None	None	3	0
				Total	9	0
2	Portland cement and natural cement	Type II, A	A	None	3	2
		Type II, A	B	None	3	3
		Type II, A	C	None	3	1
		Type II, A	D	None	3	0
		Type II, A	E	None	4	3
		Type II, A	F	None	3	3
		Type I, B	A	None	3	2
		Type I, B	B	None	3	2
		Type I, B	C	None	3	2*
		Type I, B	E	None	3	3
		Type I, B	F	None	3	3
		Type II, C	A	None	3	1
		Type II, C	B	None	3	1
		Type II, C	C	None	3	1
		Type II, C	D	None	3	0
		Type II, C	E	None	3	3
		Type II, C	F	None	3	3
				Total	52	33
3	Portland cement and neutralized resin	Type II, A	None	Yes	3	3
		Type I, B	None	Yes	3	3
		Type II, C	None	Yes	3	3
				Total	9	9
4	Portland cement and natural cement with interground resin	Type II, A	D	0.05%	3	0
		Type II, C	D	0.05%	3	0
		Type II, A	D	0.10%	3	3
		Type II, C	D	0.10%	3	1
		Type II, A	D	0.15%	3	1
		Type II, C	D	0.15%	3	2
		Type II, A	D	0.20%	3	3
		Type II, C	D	0.20%	3	2
				Total	24	12

* One specimen returned to laboratory in 1958. One specimen broken in handling in 1957.

Findings

a. All of the columns made with plain portland cement alone failed during the exposure except for one column. This one column survived for 16 winters (1958) and then the exposure was discontinued and the specimen was returned to the laboratory.

b. Over 60 percent (33) of the columns made with blends of plain portland cement and natural cement survived the 25 winters of exposure.

c. All nine of the columns made with plain portland cement plus neutralized resin survived the 25 winters.

d. Fifty percent (12 columns) of the specimens made with plain portland cement plus natural cement with interground resin survived the exposure.

e. Fifty-four of the ninety-four columns remained after the exposure period. All of these columns contained some form of air-entraining agent. This reemphasizes the previously established fact that air-entraining is required for a severe outdoor exposure involving freezing-and-thawing.

f. Columns made with natural cements F and E had the greatest durability for columns made with a blend of plain portland cement and natural cement.

(Issued Sept 1967)

Table 1-CRN

Program 13

Record of Testing of Concrete Columns, Natural Cement Investigation

1942-1966 (Installed October 1942)

				1942-1952 Readings										
Specimen	Type Cement	Cement Factor bags/ cu yd	Air* %	0 Cycles 1942 %E	187 Cycles 1943 %E	330 Cycles 1944 %E	440 Cycles 1945 %E	545 Cycles 1946 %E	663 Cycles 1947 %E	794 Cycles 1948 %E	899 Cycles 1949 %E	1060 Cycles 1950 %E	1149 Cycles 1951 %E	1250 Cycles 1952 %E
1A	II, A	7.00-	0.00	100	F**									
1B		7.15		100	F									
1C				100	105	108	F							
2A	I, B	7.00-	0.00	100	115	121	123	133	139	129	126	131	135	140
2B		7.15		100	106	112	111	123	129	120	118	120	121	124
2C				100	110	Discarded†								
3A	II, C	7.00-	0.00	100	F									
3B		7.15		100	113	F								
3C				100	110	F								
4A	II, A + nat	6.75-	1.35	100	113	117	120	126	133	123	123	122	118	122
4B	A	7.00		100	110	117	119	128	134	124	122	124	102	127
4C				100	119	127	129	135	141	131	128	128	128	130
5A	I, B + nat	6.75-	1.35	100	114	120	126	132	117	128	126	129	133	135
5B	A	7.00		100	110	115	119	125	132	123	121	123	125	128
5C				100	110	117	120	126	132	122	119	120	122	124
6A	II, C + nat	6.75-	1.34	100	115	123	126	134	F					
6B	A	7.00		100	112	118	117	129	136	50F				
6C				100	114	123	125	131	131	124	121	121	101	123
7A	II, A + nat	6.75-	3.99	100	114	121	123	132	139	127	126	129	132	133
7B	B	7.00		100	119	126	126	134	141	130	129	130	132	133
7C				100	116	124	125	133	135	126	125	126	126	129
8A	I, B + nat	6.75-	4.13	100	110	117	120	126	132	123	122	124	126	129
8B	B	7.00		100	115	123	126	133	139	129	128	129	131	134
8C				100	113	119	123	128	132	125	118	121	123	124
9A	II, C + nat	6.75-	2.02	100	115	121	124	130	138	128	126	127	130	132
9B	B	7.00		100	109	115	117	125	123	43F				
9C				100	116	128	126	117	108	50F				
10A	II, A + nat	6.75-	1.75	100	107	118	43F							
10B	C	7.00		100	112	118	120	126	132	120	118	120	122	125
10C				100	111	116	100	78	50F					
11A	I, B + nat	6.75-	0.94	100	107	112	116	122	127	118	115	118	123	128
11B	C	7.00		100	111	116	118	127	130	123	120	121	124	127
11C				100	114	121	124	129	131	120	117	119	119	119
12A	II, C + nat	6.75-	1.21	100	113	118	116	128	121	45F				
12B	C	7.00		100	115	121	122	133	137	127	130	128	127	133
12C				100	109	47F								
13A	II, A + Nat	6.75-	0.00	100	F									
13B	D	7.00		100	97	F								
13C				100	97	Discarded†								
14A	II, C + nat	6.75-	0.00	100	F									
14B	D	7.00		100	105	114	112	49F						
14C				100	56	F								
15A	II, A + nat	6.65-	0.27	100	113	123	F							
15B	D w/0.05%	6.75		100	111	116	115	128	103	49F				
15C	resin			100	116	Discarded†								
16A	II, C + nat	6.65-	1.21	100	95	F								
16B	D w/0.05%	6.75		100	112	119	117	130	48F					
16C	resin			100	110	122	121	117	102	35F				
17A	II, A + nat	6.65-	1.05	100	114	121	121	133	138	127	126	128	130	133
17B	D w/0.10%	6.75		100	118	122	121	133	138	127	125	125	127	129
17C	resin			100	108	113	112	124	127	118	115	112	113	113
18A	II, C + nat	6.65-	1.62	100	111	117	119	130	134	126	123	120	97	50F
18B	D w/0.10%	6.75		100	115	Discarded†								
18C	resin			100	108	112	112	122	127	116	115	115	117	117

(Continued)

* The percent air listed in this table is the amount of air purposefully entrained and is over and above the air entrapped during concreting operations. The percent air entrapped is estimated to be 2% for these specimens.

** F = failed.

† Specimen was installed in two pieces (broken), and exposure was discontinued in 1943.

Table 1-CRN (Continued)

Specimen	Type Cement	Cement Factor bags/cu yd	Air* %	0 Cycles 1942 %E	187 Cycles 1943 %E	330 Cycles 1944 %E	440 Cycles 1945 %E	545 Cycles 1946 %E	663 Cycles 1947 %E	794 Cycles 1948 %E	899 Cycles 1949 %E	1060 Cycles 1950 %E	1149 Cycles 1951 %E	1250 Cycles 1952 %E
				1942-1952 Readings										
19A	II, A + nat	6.65-	0.94	100	118	121	124	131	135	129	125	123	126	128
19B	D w/0.15%	6.75		100	116	121	122	129	134	49F				
19C	resin			100	109	112	112	123	129	120	117	119	121	123
20A	II, C + nat	6.65-	1.41	100	121	126	128	139	144	134	130	125	117	50F
20B	D w/0.15%	6.75		100	114	119	122	131	134	124	123	124	126	127
20C	resin			100	111	115	118	126	132	123	120	121	123	124
21A	II, A + nat	6.65-	1.45	100	116	120	122	132	135	125	124	126	128	131
21B	D w/0.20%	6.75		100	114	119	122	131	133	123	121	122	125	126
21C	resin			100	111	115	117	127	131	123	120	122	125	126
22A	II, C + nat	6.65-	1.82	100	117	122	123	135	140	131	132	130	132	135
22B	D w/0.20%	6.75		100	114	118	121	135	132	126	F			
22C	resin			100	113	118	118	128	133	125	123	123	123	125
23A	II, A + nat	6.75-	1.89	100	121	125	127	137	141	132	131	132	134	136
23B	E	7.00		100	117	121	123	132	136	127	124	124	127	127
23C				100	114	121	121	132	134	124	121	123	123	123
23CA				100	100	Discarded†								
24A	I, B + nat	6.75-	2.05	100	107	112	113	122	127	118	117	119	122	124
24B	E	7.00		100	112	118	120	129	135	122	120	122	124	126
24C				100	110	114	117	125	129	119	117	119	121	122
25A	II, C + nat	6.75-	1.52	100	110	115	117	127	132	122	120	123	125	128
25B	E	7.00		100	114	120	122	130	135	123	122	123	123	124
25C				100	109	115	116	124	128	119	117	118	120	120
26A	II, A + nat	6.75-	2.57	100	110	116	116	126	129	121	121	123	125	127
26B	F	7.00		100	114	119	123	128	133	124	121	121	124	124
26C				100	112	117	119	126	132	120	120	121	123	124
27A	I, B + nat	6.75-	1.95	100	106	110	112	122	125	117	115	118	119	121
27B	F	7.00		100	112	116	119	128	132	122	120	122	125	125
27C				100	108	114	116	124	126	118	118	117	119	120
28A	II, C + nat	6.75-	2.42	100	112	118	120	129	135	125	123	126	128	130
28B	F	7.00		100	112	118	120	130	133	123	121	124	125	127
28C				100	109	114	117	125	128	119	116	118	119	120
29A	II, A + neu-	6.55	1.62	100	111	115	117	131	131	122	119	121	128	124
29B	tralized			100	112	116	120	135	133	119	117	121	126	123
29C	resin			100	109	114	117	132	130	120	119	121	127	123
30A	I, B + neu-	6.55	1.00	100	108	112	114	128	129	120	116	115	125	124
30B	tralized			100	115	120	124	138	135	125	124	126	133	130
30C	resin			100	107	113	114	128	127	118	115	117	125	120
31A	II, C + neu-	6.55	1.61	100	111	119	122	135	136	127	126	127	136	132
31B	tralized			100	110	115	118	133	130	120	117	119	124	122
31C	resin			100	110	115	117	132	130	121	118	120	126	121

Specimen	Type Cement	Cement Factor bags/cu yd	Air* %	1335 Cycles 1953 %E	1335 Cycles 1953 Pulse Veloc fps	1335 Cycles 1953 %V^2	1446 Cycles 1954 %E	1446 Cycles 1954 %V^2	1591 Cycles 1955 %E	1591 Cycles 1955 %V^2	1758 Cycles 1956 %E	1758 Cycles 1956 %V^2	1902 Cycles 1957 %E	1902 Cycles 1957 %V^2	1973 Cycles 1958 %E	1973 Cycles 1958 %V^2	2123 Cycles 1959 %E	2123 Cycles 1959 %V^2	2194 Cycles 1960 %E	2194 Cycles 1960 %V^2
				1953-1960 Readings																
2A	I, B	7.00-	0.00	50F																
2B		7.15		128	16,130	100	134	99	137	101	137	96	137	98	140	98	Returned to lab 1958			
4A	II, A + nat	6.75-	1.35	123	15,210	100	130	99	132	102	134	100	131	99	131	100	128	96	128	99
4B	A	7.00		131	15,810	100	136	95	139	99	138	98	138	96	138	108	138	103	131	105
4C				126	15,095	100	134	97	132	100	137	98	131	97	131	--	128	--	121	--
5A	I, B + nat	6.75-	1.35	137	15,445	100	145	101	148	101	151	100	151	99	151	100	151	95	151	97
5B	A	7.00		131	15,505	100	138	98	133	102	141	98	141	98	141	100	141	96	141	99
5C				125	15,210	100	129	98	128	102	129	96	125	97	125	96	122	91	119	98
6C	II, C + nat A	6.75- 7.00	1.34	125	14,980	100	127	99	126	102	126	96	122	95	122	96	122	90	119	--
7A	II, A + nat	6.75-	3.99	132	15,265	100	141	98	143	100	144	98	144	99	144	101	141	97	141	99
7B	B	7.00		136	15,035	100	143	99	143	100	144	96	144	97	140	97	140	95	140	95
7C				130	14,760	100	135	98	133	101	132	98	132	97	129	96	132	93	129	94

(Continued)

† Specimen was installed in two pieces (broken), and exposure was discontinued in 1943.

Table 1-CRN (Continued)

Specimen	Type Cement	Cement Factor bags/cu yd	Air %	1335 Cycles 1953 %E	1335 Cycles 1953 Pulse Veloc fps	1335 Cycles 1953 $\%V^2$	1446 Cycles 1954 %E	1446 Cycles 1954 $\%V^2$	1591 Cycles 1955 %E	1591 Cycles 1955 $\%V^2$	1758 Cycles 1956 %E	1758 Cycles 1956 $\%V^2$	1902 Cycles 1957 %E	1902 Cycles 1957 $\%V^2$	1973 Cycles 1958 %E	1973 Cycles 1958 $\%V^2$	2123 Cycles 1959 %E	2123 Cycles 1959 $\%V^2$	2194 Cycles 1960 %E	2194 Cycles 1960 $\%V^2$
				1953-1960 Readings																
8A	I, B + nat B	6.75-7.00	4.13	135	14,980	100	139	99	142	102	143	99	146	100	143	101	143	99	143	100
8B				138	14,980	100	144	95	146	101	147	100	147	98	147	99	147	95	143	96
8C				125	14,925	100	130	96	129	101	128	98	128	95	121	94	124	89	121	94
9A	II, C + nat B	6.75-7.00	2.02	136	15,625	100	141	97	143	101	142	98	142	97	142	100	142	94	139	101
10B	II, A + nat C	6.75-7.00	1.75	127	15,210	100	131	96	133	102	134	97	131	91	131	88	134	--	131	--
11A	I, B + nat C	6.75-7.00	0.94	132	14,925	100	136	97	145	--	146	--	146	--	143	--	146	--	146	--
11B				130	15,625	100	135	91	137	100	136	98	136	97	136	99	139	--	136	--
11C				119	14,925	100	122	96	115	99	109	92	Broken in handling							
12B	II, C + nat C	6.75-7.00	1.21	134	15,565	100	142	97	145	101	144	98	140	95	140	100	143	95	140	96
17A	II, A + nat D w/0.10% resin	6.65-6.75	1.05	136	15,210	100	141	99	143	102	143	98	136	93	133	99	140	95	140	95
17B				133	15,325	100	135	98	137	102	134	100	128	96	128	99	135	93	132	97
17C				117	15,565	100	120	97	120	103	118	98	116	93	116	99	116	91	113	96
18C	II, C + nat D w/0.10% resin	6.65-6.75	1.62	117	15,750	100	123	98	124	99	123	98	118	94	121	98	121	91	118	93
19A	II, A + nat D w/0.15% resin	6.65-6.75	0.94	131	14,980	100	138	101	139	102	141	100	136	96	136	100	136	93	136	96
19C				125	15,505	100	128	99	130	100	128	98	126	95	126	100	126	93	123	96
20B	II, C + nat D w/0.15% resin	6.65-6.75	1.41	127	15,035	100	130	102	134	103	133	102	128	95	128	101	128	96	125	100
20C				125	15,505	100	132	100	132	100	131	98	125	95	125	100	125	95	122	97
21A	II, A + nat D w/0.20% resin	6.65-6.75	1.45	137	15,035	100	137	99	140	101	139	100	101	96	136	100	136	95	136	98
21B				122	15,210	100	132	98	134	100	133	100	130	96	133	100	130	92	127	97
21C				129	15,385	100	133	100	136	102	134	100	130	96	133	101	130	94	130	98
22A	II, C + nat D w/0.20% resin	6.65-6.75	1.82	137	15,565	100	143	98	146	100	147	98	143	96	146	100	136	94	143	98
22C				126	15,150	100	130	99	131	99	131	99	125	91	125	95	128	87	125	74
23A	II, A + nat E	6.75-7.00	1.89	138	15,150	100	143	99	144	99	144	99	137	95	140	99	140	93	137	97
23B				129	15,210	100	134	97	134	99	133	98	128	96	131	99	131	93	125	97
23C				125	14,600	100	128	95	129	99	128	99	121	95	124	98	125	92	125	93
24A	I, B + nat E	6.75-7.00	2.05	131	15,265	100	132	100	133	100	134	99	140	97	133	101	133	96	133	97
24B				121	15,210	100	131	97	132	101	131	99	131	97	131	98	128	92	125	96
24C				120	15,445	100	128	97	131	102	130	98	128	100	128	100	125	94	122	98
25A	II, C + nat E	6.75-7.00	1.52	131	15,505	100	135	96	138	101	138	98	137	98	137	96	137	95	134	100
25B				127	14,980	100	130	95	132	100	131	99	125	98	128	97	125	94	122	98
25C				122	15,150	100	124	96	126	99	122	99	120	100	120	96	117	93	114	97
26A	II, A + nat F	6.75-7.00	2.57	131	15,210	100	133	100	136	102	136	100	136	101	133	98	133	97	130	102
26B				127	14,650	100	129	98	131	99	128	99	126	100	126	96	126	95	119	99
26C				125	15,325	100	129	99	131	102	129	98	125	99	128	95	125	93	122	97
27A	I, B + nat F	6.75-7.00	1.95	124	15,505	100	129	99	132	100	132	98	132	100	132	96	129	95	126	96
27B				123	15,265	100	131	97	134	99	133	98	131	99	131	97	131	95	125	96
27C				121	15,210	100	125	101	126	101	123	98	122	99	122	95	119	94	116	95
28A	II, C + nat F	6.75-7.00	2.42	133	15,385	100	138	98	144	102	143	99	139	99	142	99	139	96	139	98
28B				130	14,925	100	132	99	136	101	133	99	133	99	133	96	130	93	127	--
28C				121	15,505	100	124	98	127	99	124	97	120	99	120	97	117	91	114	96
29A	II, A + neutralized resin	6.55	1.62	128	15,385	100	131	92	135	102	132	97	131	101	131	98	128	95	125	96
29B				123	15,325	100	129	96	133	101	129	98	126	99	126	95	120	93	120	95
29C				126	15,265	100	130	99	134	101	130	98	126	100	129	97	123	95	123	96
30A	I, B + neutralized resin	6.55	1.00	129	15,565	100	131	98	137	100	134	97	132	99	132	97	132	94	129	95
30B				131	14,980	100	137	100	143	101	140	99	139	100	139	96	139	93	136	95
30C				120	15,685	100	127	101	132	101	130	98	129	100	129	97	126	91	123	96
31A	II, C + neutralized resin	6.55	1.61	136	15,565	100	140	101	146	101	143	98	142	95	142	98	139	94	139	97
31B				122	15,505	100	128	100	133	101	128	99	124	95	127	97	124	93	121	96
31C				124	15,505	100	129	102	133	101	129	98	126	96	126	95	123	92	120	95

Table 1-CRN (Concluded)

Exposure Rack, Row 1 (W to E)

				1961-1966 Readings											
		Cement Factor		2335 Cycles 1961		2424 Cycles 1962		2530 Cycles 1963		2665 Cycles 1964		2828 Cycles 1965		2958 Cycles 1966 (Final)	
Specimen	Type Cement	bags/ cu yd	Air %	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$
4A	II, A + nat	6.75-	1.35	128	98	122	69	122	111	116	--	104	--	118	--
4B	A	7.00		131	95	125	99	125	102	125	94	125	81	134	83
4C				118	--	99	--	96	--	85	--	88	--	F	
5A	I, B + nat	6.75-	1.35	151	97	147	97	151	--	147	--	151	--	155	--
5B	A	7.00		141	97	138	98	138	82	141	--	138	--	122	--
5C				113	95	107	94	98	82	87	--	77	--	F	
6C	II, C + nat A	6.75- 7.00	1.34	116	--	110	--	107	--	104	--	98	--	98	--
7A	II, A + nat	6.75-	3.99	141	96	134	99	137	100	134	98	131	85	144	86
7B	B	7.00		140	95	133	98	136	99	129	--	126	--	123	--
7C				129	93	122	94	122	--	119	--	116	--	100	--
8A	I, B + nat B	6.75-	4.13	146	97	143	100	143	--	143	--	140	--	147	--
8B		7.00		150	96	143	96	147	100	140	--	147	--	151	--
8C				118	92	109	--	106	--	91	--	80	--	F	
9A	II, C + nat B	6.75- 7.00	2.02	142	95	135	90	135	84	132	93	129	82	145	85
10B	II, A + nat C	6.75- 7.00	1.75	131	--	128	--	125	--	125	--	122	--	113	--
11A	I, B + nat C	6.75-	0.94	149	--	142	--	145	--	142	--	136	--	149	--
11B		7.00		139	--	136	--	130	--	127	--	140	--	143	--
12B	II, C + nat C	6.75- 7.00	1.21	143	95	136	97	136	98	133	94	130	81	143	84
17A	II, A + nat	6.65-	1.05	140	95	133	98	133	98	130	--	127	--	137	--
17B	D w/0.10%	6.75		132	94	129	98	126	97	123	--	120	--	114	--
17C	resin			119	95	110	106	104	95	99	93	96	77	110	83
18C	II, C + nat D w/0.10% resin	6.65- 6.75	1.62	118	93	112	93	112	95	109	88	106	74	100	78
19A	II, A + nat	6.65-	0.94	136	96	129	99	126	105	116	--	129	--	F	
19C	D w/0.15% resin	6.75		123	95	117	98	117	98	114	97	108	80	114	86
20B	II, C + nat	6.65-	1.41	125	97	119	102	119	79	116	97	113	80	119	84
20C	D w/0.15% resin	6.75		125	96	119	95	116	100	113	94	110	83	125	84
21A	II, A + nat	6.65-	1.45	136	96	129	--	129	101	126	--	120	--	137	--
21B	D w/0.20%	6.75		127	95	121	98	124	88	121	--	115	--	121	--
21C	resin			130	96	124	99	124	93	121	91	118	82	106	86
22A	II, C + nat	6.65-	1.82	143	96	140	100	137	73	137	94	124	81	121	85
22C	D w/0.20% resin	6.75		125	86	122	85	119	89	119	90	122	--	125	--
23A	II, A + nat	6.75-	1.89	137	96	134	98	131	79	128	--	135	--	145	--
23B	E	7.00		125	95	119	96	119	90	116	--	113	--	129	--
23C				122	94	115	55	115	94	108	--	102	--	125	--
24A	I, B + nat	6.75-	2.05	133	96	130	99	130	100	130	--	130	--	140	--
24B	E	7.00		125	93	119	93	119	--	116	--	107	--	119	--
24C				125	95	119	91	119	86	116	--	101	--	95	--
25A	II, C + nat	6.75-	1.52	137	95	131	71	131	91	131	98	128	83	134	83
25B	E	7.00		122	96	123	95	123	98	120	96	117	83	111	84
25C				114	96	108	89	105	102	102	94	102	81	99	84
26A	II, A + nat	6.75-	2.57	130	98	124	98	130	93	127	98	130	83	143	83
26B	F	7.00		122	95	115	94	112	110	112	--	112	--	132	--
26C				122	95	116	96	119	102	113	95	109	76	106	84
27A	I, B + nat F	6.75-	1.95	129	95	123	96	126	95	126	93	120	83	135	86
27B		7.00		128	93	122	56	122	100	122	94	116	83	132	82
27C				119	94	110	96	113	92	107	93	107	81	125	82
28A	II, C + nat	6.75-	2.42	142	97	135	92	132	--	132	--	132	--	152	--
28B	F	7.00		130	--	120	--	120	--	120	--	117	--	136	--
28C				117	94	108	111	108	98	105	--	102	--	119	--
29A	II, A + neu-	6.55	1.62	128	94	122	96	122	101	113	96	110	85	132	82
29B	tralized			123	94	117	91	117	93	114	90	111	76	133	79
29C	resin			123	96	117	93	117	106	111	97	111	79	117	85
30A	I, B + neu-	6.55	1.00	132	95	126	103	126	95	126	96	123	81	129	91
30B	tralized			139	95	132	99	132	100	129	104	126	81	140	85
30C	resin			129	95	120	97	120	103	117	91	117	--	126	--
31A	II, C + neu-	6.55	1.61	142	95	135	91	135	101	125	96	125	61	125	82
31B	tralized			124	95	118	105	118	98	112	91	112	78	127	84
31C	resin			123	94	114	89	114	101	111	94	109	79	127	88

Resin Air-entraining Agent Program*

In October 1943, 182 concrete columns** (6 by 6 by 48 in.) were installed on the exposure rack at Treat Island as a part of this program. The purpose of this exposure was to determine the influence of resin and various amounts of resin soap, when interground with five different portland cements in commercial quantities at the mill, on the durability of concrete made with two types of coarse aggregate.

The specimens were fabricated using a natural siliceous sand as the fine aggregate and two types of coarse aggregate: a rounded siliceous gravel and a crushed traprock. The following cements were represented:

- a. Five plain portland cements
- b. Five portland cements treated with 0.03% interground resin
- c. Five portland cements treated with 0.01% interground resin soap
- d. Five portland cements treated with 0.02% interground resin soap

Data on the five cements used and the average air content of the concrete made therewith follow:

Cement	Type	C_3A, %	Average Air Contents of Concrete, %
A	206a	6.9	7.1
B	191b	13.3	5.6
C	206a	6.0	5.1
D	206a	6.0	4.7
E	206a	6.3	4.5

With the exception of the concrete made with cements containing interground resin soap, half of the series was mixed under normal air pressure (760 mm) and the other half was mixed in an atmosphere reduced to a pressure of 60 mm of mercury (vacuum).

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* See Central Concrete Laboratory, Concrete Research, Second Interim Report, Part I, "Laboratory Studies of Concrete Containing Air-entraining Admixtures" (July 1945).

** Columns are fabricated with their long axis in a vertical position.

Program 14 (Issued Sept 1967)

This exposure was terminated in 1967 after 2918 cycles of freezing-and-thawing (24 winters) with 109 specimens remaining. The final determinations of %E and $\%V^2$ were made in 1966 after 23 winters of exposure (2762 cycles of freezing-and-thawing).

The tabulation below gives mixture data and exposure record for the 60 concrete mixtures used in this investigation. Table 1-VR lists the concrete specimens fabricated and exposed as a part of this program, and gives their individual exposure record.

Mixture Data

Mix No.	Cement Type	Cement Designation	Addition	Coarse Aggregate	Pressure Mixed Under	Actual Cement Factor bags/cu yd	Water-cement Ratio gal/bag	Slump in.	Voids %	No. of Specimens Originally Installed (1943)	No. of Specimens Remaining in 1967
1A	206a	D	None	Gravel	Normal	5.38	6.0	2.2	1.3	3	0
1B	206a	E				5.35	6.0	2.25	2.0	3	0
1C	206a	A				5.32	6.0	2.5	2.6	3	1
1D	206a	C				5.37	6.2	2.7	1.5	3	0
1E	191b	B				5.33	6.2	1.9	2.0	3	0
										Total 15 for mix 1	Total 1 for mix 1
2A	206a	D	None	Gravel	Vacuum	5.38	6.0	2.0	1.1	3	0
2B	206a	E				5.35	6.0	2.0	0.9	3	0
2C	206a	A				5.32	6.0	2.1	1.3	3	0
2D	206a	C				5.37	6.2	2.3	0.8	3	0
2E	191b	B				5.33	6.2	2.0	1.4	3	0
										Total 15 for mix 2	Total 0 for mix 2
3A	206a	D	None	Traprock	Normal	5.30	7.10	2.25	2.7	3	3
3B	206a	E				5.37	7.10	2.0	2.1	3	2
3C	206a	A				5.23	7.10	2.8	4.1	3	3
3D	206a	C				5.30	7.25	2.9	2.7	3	3
3E	191b	B				5.29	7.25	2.3	2.8	3	3
										Total 15 for mix 3	Total 14 for mix 3
4A	206a	D	None	Traprock	Vacuum	5.30	7.10	2.1	1.6	3	0
4B	206a	E				5.37	7.10	2.0	0.9	3	0
4C	206a	A				5.23	7.10	2.3	2.3	3	3
4D	206a	C				5.30	7.25	2.5	1.3	3	0
4E	191b	B				5.29	7.25	2.0	2.0	3	0
										Total 15 for mix 4	Total 3 for mix 4
5A	206a	D	0.03% inter-	Gravel	Normal	5.23	5.60	2.3	4.3	3	1
5B	206a	E	ground			5.18	5.50	2.2	5.1	3	3
5C	206a	A	resin			4.95	5.35	2.9	10.0	3	2
5D	206a	C				5.22	5.75	3.1	4.3	3	3
5E	191b	B				5.17	5.70	2.7	5.5	3	0
										Total 15 for mix 5	Total 9 for mix 5
6A	206a	D	Inter-	Gravel	Vacuum	5.23	5.60	1.7	1.8	3	1
6B	206a	E	ground			5.18	5.50	1.4	2.9	3	0
6C	206a	A	resin			4.95	5.35	1.6	3.7	3	3
6D	206a	C				5.22	5.75	1.9	1.6	3	1
6E	191b	B				5.17	5.70	1.3	2.3	3	0
										Total 15 for mix 6	Total 5 for mix 6
7A	206a	D	Inter-	Traprock	Normal	5.13	6.55	3.2	6.3	3	3
7B	206a	E	ground			5.20	6.45	2.6	4.7	3	3
7C	206a	A	resin			4.78	6.0	3.7	14.1	3	2
7D	206a	C				5.20	6.60	2.75	4.8	3	3
7E	191b	B				5.12	6.50	2.9	6.3	3	3
										Total 15 for mix 7	Total 14 for mix 7

(Continued)

Mix No.	Cement Type	Cement Designation	Addition	Coarse Aggregate	Pressure Mixed Under	Actual Cement Factor bags/cu yd	Water-cement Ratio gal/bag	Slump in.	Voids %	No. of Specimens Originally Installed (1943)	No. of Specimens Remaining in 1967
8A	206a	D	Inter-	Traprock	Vacuum	5.13	6.55	2.2	2.3	3	3
8B	206a	E	ground			5.20	6.45	1.75	2.0	3	2
8C	206a	A	resin			4.78	6.0	2.0	5.9	3	3
8D	206a	C				5.20	6.60	1.6	1.3	3	3
8E	191b	B				5.12	6.50	1.5	2.7	3	3
										Total 15 for mix 8	Total 14 for mix 8
9A	206a	D	0.01%	Gravel	Normal	5.27	5.60	2.4	3.6	3	2
9B	206a	E	resin			5.25	5.60	2.0	4.0	3	3
9C	206a	A	soap			5.21	5.47	1.9	4.7	3	2
9D	206a	C				5.20	5.70	2.9	4.9	3	2
9E	191b	B				5.20	5.67	2.1	4.9	3	0
										Total 15 for mix 9	Total 9 for mix 9
10A	206a	D	0.01%	Traprock	Normal	5.18	6.48	3.0	5.1	3	3
10B	206a	E	resin			5.19	6.52	3.0	4.8	4	4
10C	206a	A	soap			5.15	5.97	1.75	5.7	3	2
10D	206a	C				5.20	6.40	3.0	4.9	3	3
10E	191b	B				5.12	6.37	2.7	6.4	3	3
										Total 16 for mix 10	Total 15 for mix 10
11A	206a	D	0.02%	Gravel	Normal	5.13	5.44	2.9	6.4	3	2
11B	206a	E	resin			5.16	5.52	2.25	5.6	3	3
11C	206a	A	soap			5.11	5.27	1.9	6.5	3	3
11D	206a	C				5.07	5.45	2.8	7.5	3	3
11E	191b	B				5.10	5.42	2.0	7.0	3	0
										Total 15 for mix 11	Total 11 for mix 11
12A	206a	D	0.02%	Traprock	Normal	5.05	6.17	3.2	8.0	4	4
12B	206a	E	resin			5.08	6.23	2.6	7.3	3	2
12C	206a	A	soap			5.01	5.80	2.25	9.0	3	3
12D	206a	C				4.97	6.00	3.1	9.8	3	3
12E	191b	B				5.00	6.10	2.6	9.6	3	2
										Total 16 for mix 12	Total 14 for mix 12
										Total 182 for all mixes	Total 109 for all mixes

Table heading: Mixture Data

Findings

a. The columns containing concrete mixed under normal air pressure had greater durability than columns made under a pressure of 60 mm of mercury (vacuum).

b. The concrete columns made with traprock as a coarse aggregate had greater durability than did columns made using gravel.

c. Of the 12 mixtures used, the mixture (mix 7) containing traprock as a coarse aggregate, mixed under normal atmospheric conditions and containing 0.03% interground resin had the best exposure record. None of the 15 columns made with this mixture failed during the exposure; however, one column was broken accidentally in handling.

d. The mixture (mix 2) using plain portland cement, containing

gravel, and mixed under a pressure of 60 mm of mercury (vacuum) had the worst exposure record. None of the 15 columns installed survived the exposure.

e. Mixtures containing 0.03% interground resin had greater durability than did mixtures containing 0.01% resin soap or mixtures made with plain cement.

f. The relative durability of 0.02% resin soap mixtures as compared with plain cement, 0.03% interground resin, and 0.01% resin soap mixtures was not clearly indicated by the exposure data.

g. The order of durability with respect to mixture was as follows (most durable to least durable): Mixture Nos. 7, 10, 8 and 3, 12, 11, 5, 9, 6, 4, 1, and 2.

h. The order of durability with respect to cement was as follows (most durable to least durable): Cement A, cement C, cement E, cement D, and cement B.

(Issued Sept 1967)

Table 1-VR

Record of Testing of Concrete Columns, Resin Air-entraining Agent Program

1943-1966 (Installed October 1943)

		1943-1954 Readings														
												1139 Cycles 1953			1250 Cycles 1954	
													Pulse			
Mix No.	Specimen No.	0 Cycles 1943 %E	142 Cycles 1944 %E	244 Cycles 1945 %E	349 Cycles 1946 %E	467 Cycles 1947 %E	598 Cycles 1948 %E	703 Cycles 1949 %E	864 Cycles 1950 %E	953 Cycles 1951 %E	1054 Cycles 1952 %E	%E	Veloc fps	$\%V^2$	%E	$\%V^2$
1A	A-1-E	100	F*													
	B-1-E	100	F													
	C-1-E	100	53	F												
2A	A-2-E	100	74	75	77	F										
	B-2-E	100	F													
	C-2-E	100	F													
3A	A-3-E	100	127	140	142	149	141	141	141	147	148	149	15,325	100	155	102
	B-3-E	100	115	122	127	132	114	126	126	129	132	138	16,195	100	137	95
	C-3-E	100	115	124	130	136	128	126	128	130	133	136	15,810	100	139	96
4A	A-4-E	100	115	129	135	142	157	135	134	140	F					
	B-4-E	100	118	124	132	140	132	132	133	139	F					
	C-4-E	100	99	110	93	106	F									
5A	A-5-E	100	117	122	130	138	126	135	132	137	139	141	15,625	100	145	96
	B-5-E	100	112	118	126	134	126	128	127	130	135	140	--	--	145	--
	C-5-E	100	116	123	131	135	132	130	128	135	137	141	15,810	100	145	95
6A	A-6-E	100	116	124	134	142	134	137	133	137	140	148	16,195	100	146	91
	B-6-E	100	83	99	110	120	111	117	122	126	F					
	C-6-E	100	97	109	119	130	123	111	104	141	F					
7A	A-7-E	100	126	139	145	158	142	143	144	146	150	153	15,210	100	157	94
	B-7-E	100	119	130	134	138	130	136	139	133	136	139	15,445	100	142	91
	C-7-E	100	123	137	142	147	139	143	147	142	146	149	15,505	100	155	95
8A	A-8-E	100	117	121	133	139	131	136	137	135	139	141	16,260	100	148	93
	B-8-E	100	121	129	139	145	137	136	138	141	145	149	16,195	100	159	92
	C-8-E	100	112	120	130	135	127	125	125	130	133	137	16,460	100	145	92
1B	A-9-E	100	F													
	B-9-E	100	F													
	C-9-E	100	F													
2B	A-10-E	100	F													
	B-10-E	100	F													
	C-10-E	100	F													
3B	A-11-E	100	111	121	127	131	126	126	129	135	F					
	B-11-E	100	117	128	134	138	131	129	129	134	137	139	16,460	100	148	92
	C-11-E	100	114	122	130	134	126	128	125	128	131	134	15,875	100	139	92
4B	A-12-E	100	109	119	125	131	124	124	136	148	F					
	B-12-E	100	F													
	C-12-E	100	F													
5B	A-13-E	100	111	118	124	131	125	124	125	129	131	134	15,875	100	141	93
	B-13-E	100	121	128	136	145	137	136	135	143	147	149	16,395	100	158	93
	B-13-E	100	116	126	132	138	130	129	130	133	136	139	16,260	100	146	90
6B	A-14-E	100	98	109	79	89	F									
	B-14-E	100	91	105	121	126	117	115	129	129	F					
	C-14-E	100	F													
7B	A-15-E	100	123	126	142	146	139	138	139	142	146	149	16,395	100	158	91
	B-15-E	100	121	133	139	143	136	134	136	139	142	146	16,000	100	156	92
	C-15-E	100	121	134	139	144	135	134	136	139	143	145	15,935	100	153	92
8B	A-16-E	100	117	125	131	139	130	129	132	135	137	141	16,665	100	149	89
	B-16-E	100	128	138	143	148	140	139	140	144	147	154	16,460	100	159	92
	C-16-E	100	110	120	124	136	128	127	128	133	F					
1C	A-17-E	100	108	112	122	129	116	116	122	128	F					
	B-17-E	100	115	119	130	135	127	126	127	130	134	137	15,265	100	147	90
	C-17-E	100	120	125	137	143	134	133	135	140	142	144	15,625	100	152	88
2C	A-18-E	100	F													
	B-18-E	100	112	122	126	131	121	121	116	120	F					
	C-18-E	100	F													

(Continued)

* F denotes that the specimen failed either by the %E dropping below 50 or by deteriorating to such an extent that testing was no longer practicable.

Table 1-VR (Continued)

Mix No.	Specimen No.	1943-1954 Readings: 0 Cycles 1943 %E	142 Cycles 1944 %E	244 Cycles 1945 %E	349 Cycles 1946 %E	467 Cycles 1947 %E	598 Cycles 1948 %E	703 Cycles 1949 %E	864 Cycles 1950 %E	953 Cycles 1951 %E	1054 Cycles 1952 %E	1139 Cycles 1953 %E	1139 Cycles 1953 Pulse Veloc fps	1139 Cycles 1953 $\%V^2$	1250 Cycles 1954 %E	1250 Cycles 1954 $\%V^2$
3C	A-19-E	100	132	142	146	151	142	141	141	144	148	152	15,040	100	159	90
	B-19-E	100	125	134	138	142	134	134	134	137	139	143	14,925	100	151	94
	C-19-E	100	123	132	136	140	132	131	132	135	139	144	15,325	100	149	93
4C	A-20-E	100	128	132	142	146	139	137	138	135	144	149	15,265	100	154	91
	B-20-E	100	126	128	138	144	137	133	135	137	142	147	15,210	100	154	93
	C-20-E	100	126	130	140	147	138	134	138	135	143	148	15,565	100	156	90
5C	A-21-E	100	131	141	146	151	143	142	141	146	150	155	15,095	100	163	88
	B-21-E	100	126	140	147	138	142	139	143	145	150	153	14,815	100	159	93
	C-21-E	100	134	141	150	156	148	146	146	149	154	159	14,760	100	124	90
6C	A-22-E	100	125	130	142	149	142	139	140	142	147	150	15,810	100	154	90
	B-22-E	100	124	128	138	147	139	138	139	144	147	149	16,130	100	153	93
	C-22-E	100	127	134	145	154	144	143	144	146	150	154	16,065	100	155	90
7C	A-23-E	100	129	141	147	151	142	141	143	145	148	156	14,085	100	160	92
	B-23-E	100	137	143	152	161	154	151	154	156	160	166	14,705	100	171	91
	C-23-E	100	144	Broken in handling November 1944												
8C	A-24-E	100	129	142	147	152	142	141	142	145	150	153	15,505	100	159	93
	B-24-E	100	131	144	150	154	146	144	146	148	152	160	15,875	100	164	94
	C-24-E	100	137	153	150	163	155	153	154	157	162	167	15,685	100	173	94
1D	A-25-E	100	F													
	B-25-E	100	119	119	F											
	C-25-E	100	F													
2D	A-26-E	100	F													
	B-26-E	100	F													
	C-26-E	100	F													
3D	A-27-E	100	136	139	149	158	150	148	150	151	156	158	15,325	100	165	93
	B-27-E	100	136	148	154	158	149	147	149	151	155	160	15,385	100	166	94
	C-27-E	100	131	140	145	153	142	141	140	142	146	152	15,325	100	153	96
4D	A-28-E	100	112	116	102	109	F									
	B-28-E	100	120	132	129	138	140	F								
	C-28-E	100	119	130	136	145	135	136	132	133	F					
5D	A-29-E	100	119	131	134	141	133	133	133	135	141	143	15,875	100	145	94
	B-29-E	100	117	130	135	140	131	131	131	132	136	139	15,625	100	144	95
	C-29-E	100	132	144	149	156	148	146	147	148	154	156	15,875	100	162	95
6D	A-30-E	100	120	132	138	144	136	134	135	137	141	144	16,065	100	153	95
	B-30-E	100	F													
	C-30-E	100	F													
7D	A-31-E	100	142	151	155	151	163	160	163	165	171	174	15,935	100	184	97
	B-31-E	100	125	132	143	148	140	138	140	143	146	149	15,505	100	157	96
	C-31-E	100	138	144	157	163	153	152	153	157	161	165	15,625	100	174	95
8D	A-32-E	100	133	140	151	158	149	147	149	152	156	160	15,625	100	169	99
	B-32-E	100	124	129	138	146	137	136	137	141	143	146	16,000	100	153	95
	B-32-E	100	130	138	146	156	147	145	147	151	154	158	16,260	100	164	93
1E	A-33-E	100	119	111	137	141	134	133	135	137	140	144	15,150	100	148	94
	B-33-E	100	115	106	131	137	127	123	110	103	96	F				
	C-33-E	100	112	102	127	132	124	121	120	128	F					
2E	A-34-E	100	114	127	133	137	130	128	123	129	F					
	B-34-E	100	113	124	131	135	128	F								
	C-34-E	100	111	119	126	132	115	98	F							
3E	A-35-E	100	125	133	138	143	134	132	134	137	141	144	14,870	100	151	101
	B-35-E	100	120	128	132	137	128	126	128	131	135	138	15,150	100	144	98
	C-35-E	100	118	126	130	134	117	126	127	129	132	138	15,150	100	141	96
4E	A-36-E	100	123	134	138	144	134	133	134	139	142	145	15,325	100	153	94
	B-36-E	100	117	128	131	135	129	125	127	127	133	135	15,040	100	139	100
	C-36-E	100	123	132	135	140	131	128	129	130	135	140	15,265	100	147	96
5E	A-37-E	100	121	132	137	142	134	132	132	135	138	141	14,650	100	151	--
	B-37-E	100	123	135	140	145	138	135	135	135	140	140	15,445	100	146	93
	C-37-E	100	120	131	137	142	134	131	132	132	134	134	15,445	100	135	92

(Continued)

Table 1-VR (Continued)

		1943-1954 Readings														
												1139 Cycles 1953			1250 Cycles 1954	
Mix No.	Speci-men No.	0 Cycles 1943 %E	142 Cycles 1944 %E	244 Cycles 1945 %E	349 Cycles 1946 %E	467 Cycles 1947 %E	598 Cycles 1948 %E	703 Cycles 1949 %E	864 Cycles 1950 %E	953 Cycles 1951 %E	1054 Cycles 1952 %E	%E	Pulse Veloc fps	$\%V^2$	%E	$\%V^2$
6E	A-38-E	100	121	133	140	146	136	134	136	140	F					
	B-38-E	100	118	128	134	140	132	130	139	139	F					
	C-38-E	100	128	142	148	154	145	142	146	150	F					
7E	A-39-E	100	137	147	152	158	148	147	149	153	155	159	15,210	100	169	97
	B-39-E	100	126	134	138	144	134	133	134	138	140	144	15,565	100	153	90
	C-39-E	100	137	146	151	163	147	148	145	146	150	153	14,980	100	160	96
8E	A-40-E	100	132	141	146	153	145	142	143	147	150	155	15,935	100	163	92
	B-40-E	100	121	131	135	140	132	130	132	133	136	144	15,935	100	153	95
	C-40-E	100	124	135	141	147	137	135	132	135	138	141	15,685	100	146	97
9A	A-41-E	100	114	115	117	125	124	124	126	125	123	133	--	--	138	--
	B-41-E	100	117	129	135	142	133	131	131	135	135	141	16,130	100	150	88
	C-41-E	100	119	131	138	144	138	138	132	136	137	141	16,260	100	146	91
10A	A-42-E	100	117	128	133	139	129	134	129	132	135	138	15,750	100	142	94
	B-42-E	100	116	128	132	139	129	127	129	132	135	138	16,325	100	144	91
	C-42-E	100	116	127	132	139	129	127	128	132	134	137	16,460	100	144	91
11A	A-43-E	100	113	122	128	134	126	124	125	128	131	134	15,445	100	138	93
	B-43-E	100	117	129	135	142	133	132	132	135	136	140	15,935	100	149	92
	C-43-E	100	122	135	139	147	138	136	138	141	144	146	15,935	100	152	91
12A	A-44-E	100	119	128	135	140	132	130	131	134	137	140	15,150	100	145	94
	B-44-E	100	116	125	131	136	127	127	127	130	134	136	15,750	100	143	93
	C-44-E	100	119	125	133	139	132	130	131	135	137	140	15,625	100	145	93
	D-44-E	100	130	137	145	151	144	142	143	146	148	151	15,385	100	148	96
9B	A-45-E	100	111	121	125	131	124	121	118	120	118	123	15,750	100	125	95
	B-45-E	100	110	122	128	131	124	121	118	120	121	123	15,445	100	129	101
	C-45-E	100	112	123	127	133	125	128	123	126	126	127	15,385	100	132	96
10B	A-46-E	100	119	132	137	143	135	134	135	138	141	144	15,875	100	148	95
	B-46-E	100	112	123	127	132	124	126	124	127	129	131	16,000	100	137	95
	C-46-E	100	112	123	127	131	123	126	128	129	125	134	15,445	100	140	98
	D-46-E	100	118	129	123	138	131	129	130	133	135	137	15,750	100	144	98
11B	A-47-E	100	116	127	132	137	130	129	131	131	137	139	15,505	100	146	97
	B-47-E	100	113	124	127	133	126	124	125	128	127	133	15,935	100	140	94
	C-47-E	100	111	124	125	129	128	126	121	122	124	132	15,505	100	129	95
12B	A-48-E	100	116	129	132	137	130	132	130	128	135	139	15,445	100	145	96
	B-48-E	100	113	114	115	122	117	117	119	119	121	127	--	--	128	--
	C-48-E	100	114	126	129	134	125	123	124	122	129	133	15,385	100	137	107
9C	A-49-E	100	109	122	124	127	121	121	121	124	126	129	15,445	100	135	100
	B-49-E	100	111	125	125	130	122	120	120	123	125	131	15,210	100	132	101
	C-49-E	100	110	119	124	129	121	120	121	122	123	125	15,325	100	126	98
10C	A-50-E	100	120	131	129	140	131	130	132	135	137	140	15,325	100	145	100
	B-50-E	100	F													
	C-50-E	100	116	125	135	134	125	123	127	127	128	131	15,325	100	136	99
11C	A-51-E	100	108	118	122	127	120	118	127	120	121	124	15,325	100	127	98
	B-51-E	100	110	120	124	130	123	123	123	127	128	131	15,445	100	137	98
	C-51-E	100	109	126	130	135	127	125	120	130	129	132	15,265	100	133	96
12C	A-52-E	100	117	126	129	134	126	123	124	126	128	132	15,040	100	138	99
	B-52-E	100	121	131	134	140	132	130	131	134	135	140	14,760	100	146	101
	C-52-E	100	123	127	137	141	133	131	132	133	136	140	14,925	100	146	100
9D	A-53-E	100	112	124	129	134	126	125	127	129	131	134	15,265	100	138	99
	B-53-E	100	112	118	126	131	121	F								
	C-53-E	100	116	128	135	140	134	132	132	135	137	140	15,685	100	145	95
10D	A-54-E	100	117	127	132	137	129	128	130	132	134	138	15,505	100	146	97
	B-54-E	100	116	126	130	134	126	123	124	126	127	130	15,210	100	134	99
	C-54-E	100	118	124	133	138	129	128	129	125	132	134	15,445	100	143	98
11D	A-55-E	100	113	125	128	134	126	124	126	129	131	133	15,505	100	138	95
	B-55-E	100	110	121	124	129	121	120	118	121	121	122	14,650	100	134	113
	C-55-E	100	111	123	126	125	124	122	123	124	125	93	15,035	100	130	99
12D	A-56-E	100	121	133	137	134	135	133	133	142	138	142	14,980	100	147	99
	B-56-E	100	119	129	133	130	129	127	129	136	132	135	14,870	100	139	99
	C-56-E	100	116	126	130	134	126	125	126	134	130	133	14,815	100	137	99

(Continued)

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Table 1-VR (Continued)

Mix No.	Specimen No.	1943-1954 Readings: 0 Cycles 1943 %E	142 Cycles 1944 %E	244 Cycles 1945 %E	349 Cycles 1946 %E	467 Cycles 1947 %E	598 Cycles 1948 %E	703 Cycles 1949 %E	864 Cycles 1950 %E	953 Cycles 1951 %E	1054 Cycles 1952 %E	1139 Cycles 1953 %E	1139 Cycles 1953 Pulse Veloc fps	1139 Cycles 1953 $\%V^2$	1250 Cycles 1954 %E	1250 Cycles 1954 $\%V^2$
9E	A-57-E	100	111	122	125	129	121	119	118	115	108	115	14,760	100	100	99
	B-57-E	100	109	120	122	125	116	116	110	107	110	111	14,490	100	110	71
	C-57-E	100	111	121	123	129	121	119	119	122	122	132	--	--	141	--
10E	A-58-E	100	116	126	128	132	125	123	123	126	127	130	14,870	100	135	101
	B-58-E	100	115	122	124	128	118	117	116	117	118	119	14,705	100	125	100
	C-58-E	100	114	123	126	129	122	119	120	128	124	132	15,035	100	144	99
11E	A-59-E	100	109	119	123	127	120	117	117	119	118	119	14,760	100	133	101
	B-59-E	100	106	115	117	119	109	107	103	99	101	104	14,335	100	143	99
	C-59-E	100	109	117	119	123	116	115	112	109	113	118	14,495	100	122	94
12E	A-60-E	100	112	120	123	127	120	117	119	120	121	124	14,495	100	133	100
	B-60-E	100	112	118	118	120	108	109	104	105	100	115	13,795	100	112	117
	C-60-E	100	117	124	126	128	123	126	121	122	124	128	14,440	100	136	102

Mix No.	Specimen No.	1955-1965 Readings: 1395 Cycles 1955 %E	$\%V^2$	1562 Cycles 1956 %E	$\%V^2$	1706 Cycles 1957 %E	$\%V^2$	1777 Cycles 1958 %E	$\%V^2$	1927 Cycles 1959 %E	$\%V^2$	1998 Cycles 1960 %E	$\%V^2$	2139 Cycles 1961 %E	$\%V^2$	2228 Cycles 1962 %E	$\%V^2$	2334 Cycles 1963 %E	$\%V^2$	2469 Cycles 1964 %E	$\%V^2$	2632 Cycles 1965 %E	$\%V^2$
3A	A-3-E	160	94	166	97	166	96	174	98	162	94	158	96	162	95	154	96	158	98	154	--	154	--
	B-3-E	145	92	151	94	151	93	158	94	148	88	148	92	148	91	148	88	148	94	148	89	141	93
	C-3-E	146	94	151	98	147	96	157	97	147	91	144	94	147	95	144	95	141	95	138	93	132	101
5A	A-5-E	152	92	157	--	114	--	114	--	149	--	146	--	153	--	150	--	153	--	150	--	F	
	B-5-E	155	--	163	--	F																	
	C-5-E	150	93	154	--	154	--	163	--	152	--	149	--	152	--	145	--	145	--	138	--	135	--
6A	A-6-E	152	92	158	89	158	95	169	96	151	87	151	92	151	92	148	95	148	90	145	84	145	--
7A	A-7-E	164	94	168	91	174	94	178	96	166	91	162	95	166	94	162	93	162	94	162	93	158	97
	B-7-E	148	91	151	91	154	94	162	94	151	89	147	91	151	92	144	91	144	93	144	86	144	91
	C-7-E	158	95	163	93	157	95	172	95	160	90	156	93	160	94	156	95	156	95	156	91	152	97
8A	A-8-E	152	95	156	97	155	94	162	94	155	90	151	93	155	93	148	96	148	92	148	91	148	95
	B-8-E	160	95	166	95	166	--	177	--	169	--	169	--	173	--	169	--	169	--	169	--	165	--
	C-8-E	147	94	150	94	142	94	152	95	145	86	145	76	148	92	141	92	141	--	141	--	138	--
3B	B-11-E	150	92	155	92	151	91	162	92	151	87	148	88	151	89	148	--	148	--	148	--	148	--
	C-11-E	142	95	146	95	149	95	153	94	143	89	140	92	143	95	140	95	137	--	137	--	137	--
5B	A-13-E	142	94	147	97	106	96	129	97	135	91	135	94	141	95	138	95	138	98	132	83	132	--
	B-13-E	162	94	141	94	169	93	151	94	154	88	158	90	165	92	161	94	165	--	161	--	161	--
	C-13-E	147	90	147	92	162	88	155	85	145	83	142	86	149	88	146	93	146	--	143	--	146	--
7B	A-15-E	160	92	165	93	162	90	162	93	162	92	158	93	165	90	158	94	154	90	154	--	154	--
	B-15-E	157	94	160	95	160	94	160	90	156	88	156	92	160	92	153	97	153	94	153	--	153	--
	C-15-E	156	94	160	95	159	94	166	93	159	84	155	93	159	93	155	95	155	92	155	90	151	--
8B	A-16-E	152	91	157	92	154	91	161	90	154	87	151	88	154	90	147	92	150	91	143	75	143	90
	B-16-E	160	93	170	93	165	93	169	90	158	88	154	90	158	91	154	89	150	--	150	--	146	--
1C	B-17-E	146	107	149	91	F																	
	C-17-E	147	94	154	93	148	88	155	87	141	--	138	--	152	--	156	--	152	--	152	--	148	--
3C	A-19-E	161	94	166	94	167	94	171	91	163	89	163	90	167	92	163	92	167	--	167	--	163	--
	B-19-E	150	94	153	96	149	93	157	92	149	91	145	93	149	92	145	--	145	--	145	--	141	--
	C-19-E	153	93	156	95	156	92	164	91	156	88	152	91	156	93	152	94	152	92	148	92	148	94
4C	A-20-E	157	94	160	96	157	93	165	92	157	89	153	92	157	93	153	97	149	--	149	--	145	--
	B-20-E	156	94	159	95	151	96	166	94	158	91	154	92	154	93	150	--	154	--	154	--	150	--
	C-20-E	157	95	163	90	157	90	168	91	160	86	156	90	160	89	156	92	156	89	156	--	156	--
5C	A-21-E	163	93	166	90	160	89	164	89	148	85	144	87	144	89	144	90	140	95	129	--	125	--
	B-21-E	162	96	168	99	157	93	169	93	153	88	149	92	153	92	149	94	149	102	145	87	141	90
	C-21-E	136	92	151	92	134	90	149	90	130	87	F											
6C	A-22-E	155	93	161	95	152	90	167	91	149	88	142	90	149	89	142	87	142	89	132	85	132	87
	B-22-E	155	95	162	92	156	93	170	89	152	86	149	89	152	89	149	96	156	--	153	--	150	--
	C-22-E	154	90	161	86	152	85	163	84	136	80	133	81	136	80	129	71	122	--	125	--	122	--
7C	A-23-E	162	94	166	97	166	91	170	93	166	91	166	93	170	91	157	53	153	94	153	88	149	93
	B-23-E	176	91	181	92	178	91	192	90	178	88	174	92	174	103	170	93	170	85	170	88	166	89

(Continued)

Table 1-VR (Continued)

		1955-1965 Readings																					
		1395 Cycles 1955		1562 Cycles 1956		1706 Cycles 1957		1777 Cycles 1958		1927 Cycles 1959		1998 Cycles 1960		2139 Cycles 1961		2228 Cycles 1962		2334 Cycles 1963		2469 Cycles 1964		2632 Cycles 1965	
Mix No.	Specimen No.	%E	%V^2	%E	%V^2	%E	%V^2	%E	%V^2	%E	%V^2	%E	%V^2	%E	%V^2	%E	%V^2	%E	%V^2	%E	%V^2	%E	%V^2
8C	A-24-E	163	95	169	96	159	94	175	94	167	91	159	92	163	93	159	96	155	98	155	83	151	93
	B-24-E	168	95	175	94	174	90	182	93	170	91	166	93	170	92	166	89	162	84	166	90	158	91
	C-24-E	176	94	184	96	179	91	192	93	179	90	175	94	179	92	171	92	171	96	171	91	167	93
3D	A-27-E	168	95	161	95	182	92	182	93	169	91	169	92	173	93	165	95	169	--	169	--	161	--
	B-27-E	166	94	171	92	171	89	184	92	167	88	163	91	176	92	168	--	172	--	172	--	168	--
	C-27-E	159	97	165	98	159	94	171	94	159	91	155	94	163	96	151	96	155	--	155	--	163	--
5D	A-29-E	144	94	146	94	144	90	147	91	137	85	134	88	140	--	137	--	137	--	128	--	128	--
	B-29-E	142	95	150	97	149	89	153	93	146	88	143	--	146	--	143	--	143	--	136	--	133	--
	C-29-E	161	93	169	95	159	91	178	92	163	87	159	--	163	--	156	--	160	--	149	--	145	--
6D	A-30-E	149	92	157	95	152	90	166	93	152	87	149	90	149	--	149	--	149	--	142	--	145	--
7D	A-31-E	186	94	195	96	192	92	205	93	192	90	188	91	192	--	188	--	188	--	188	--	188	--
	B-31-E	157	96	163	94	162	93	170	93	158	86	154	88	158	94	154	98	154	97	154	92	150	94
	C-31-E	173	95	181	97	179	92	188	93	175	91	171	92	175	94	171	100	171	97	167	89	163	93
8D	A-32-E	169	98	177	100	175	95	179	95	175	90	171	95	175	96	167	103	171	81	167	95	163	94
	B-32-E	152	95	151	96	147	90	150	93	143	86	140	91	147	--	144	--	151	--	141	--	141	--
	C-32-E	166	93	177	95	173	91	181	--	173	--	169	--	173	--	169	--	165	--	165	--	161	--
1E	A-33-E	155	--	131	--	F																	
3E	A-35-E	154	98	162	98	156	--	172	--	172	--	168	--	180	--	176	--	184	--	188	--	192	--
	B-35-E	147	98	144	99	142	93	163	--	170	--	170	--	189	--	189	--	205	--	222	--	244	--
	C-35-E	144	94	153	96	157	91	157	92	157	--	157	--	165	--	165	--	169	--	216	--	190	--
4E	A-36-E	158	89	171	--	173	--	193	--	201	--	232	--	286	--	F							
	B-36-E	140	96	145	99	142	95	149	97	145	--	145	--	170	--	166	--	148	--	162	--	177	--
	C-36-E	146	--	144	--	148	--	162	--	155	--	103	--	F									
5E	A-37-E	157	--	143	--	137	--	143	--	131	--	125	--	140	--	137	--	128	--	137	--	140	--
	B-37-E	136	87	134	--	95	--	136	--	130	--	146	--	195	--	Broken in handling							
	C-37-E	127	89	134	90	115	80	106	77	115	--	118	--	F									
7E	A-39-E	167	93	175	97	125	93	176	95	176	93	168	95	172	96	168	97	168	97	164	93	164	--
	B-39-E	150	87	156	87	109	90	154	90	154	86	147	92	154	91	147	93	147	93	147	88	143	93
	C-39-E	159	94	167	97	165	85	173	95	165	91	161	94	165	95	157	96	161	96	157	89	157	88
8E	A-40-E	164	89	160	--	159	--	178	--	174	--	170	--	182	--	186	--	194	--	198	--	194	--
	B-40-E	148	103	156	96	159	92	170	--	159	--	155	--	162	--	162	--	166	--	162	--	158	--
	C-40-E	159	95	161	95	162	94	166	95	158	90	158	90	162	--	158	--	129	--	158	--	162	--
9A	A-41-E	138	--	F																			
	B-41-E	158	88	163	--	163	--	171	--	164	--	168	--	179	--	175	--	175	--	175	--	175	--
	C-41-E	150	90	153	90	153	--	156	--	142	--	135	--	132	--	126	--	114	--	111	--	105	--
10A	A-42-E	151	93	151	92	151	--	163	--	152	90	148	93	152	90	148	95	141	93	141	88	137	86
	B-42-E	151	91	151	87	151	90	151	90	144	87	147	91	161	87	147	95	144	95	144	82	141	98
	C-42-E	152	92	152	90	153	91	118	91	150	88	147	91	154	91	147	102	147	86	147	--	144	--
11A	A-43-E	147	93	147	--	143	--	150	--	117	--	120	--	130	--	127	--	114	--	105	--	109	--
	B-43-E	152	92	155	89	154	92	137	98	147	87	140	90	150	90	143	94	140	95	130	86	130	97
	C-43-E	155	92	161	86	156	88	142	93	149	87	146	90	153	92	149	89	149	91	F			
12A	A-44-E	152	96	154	92	157	95	165	96	153	93	149	96	153	95	146	98	146	--	146	--	146	--
	B-44-E	147	94	150	91	150	92	161	95	147	89	144	92	147	92	144	96	144	95	141	92	138	94
	C-44-E	153	94	154	91	141	93	162	94	151	89	147	94	154	93	147	95	144	95	144	93	141	95
	D-44-E	164	95	166	--	163	--	175	--	159	90	155	94	163	93	155	91	151	95	151	94	147	97
9B	A-45-E	124	95	128	--	134	--	134	--	128	--	119	--	128	--	128	--	116	--	107	--	104	--
	B-45-E	132	100	133	94	135	100	138	102	132	93	117	100	126	99	126	101	123	--	106	--	100	--
	C-45-E	137	96	137	--	138	--	148	--	135	--	129	--	142	--	135	--	132	--	129	--	129	--
10B	A-46-E	165	95	162	90	161	93	172	97	161	91	157	95	164	95	157	97	157	78	157	92	153	94
	B-46-E	145	95	144	90	140	94	153	98	136	92	136	93	142	94	132	95	132	97	132	95	129	96
	C-46-E	144	98	143	94	141	97	151	99	137	95	134	96	137	97	130	99	130	99	127	94	124	96
	D-46-E	152	98	151	94	153	95	164	96	139	89	146	95	150	96	143	98	143	95	140	94	137	95
11B	A-47-E	156	99	156	97	151	97	173	100	155	93	151	96	158	98	151	100	151	98	148	93	145	95
	B-47-E	147	95	146	94	149	--	156	--	139	--	136	--	142	--	139	--	136	--	127	--	130	--
	C-47-E	134	97	144	97	142	94	152	98	129	91	132	97	135	95	132	91	129	97	126	89	126	95
12B	A-48-E	155	97	155	96	147	96	169	100	151	95	151	99	162	98	151	101	147	101	147	99	144	95
	B-48-E	132	--	F																			
	C-48-E	144	95	146	--	144	--	155	--	141	97	141	104	144	96	137	98	137	98	137	--	134	--

(Continued)

Table 1-VR (Continued)

Mix No.	Specimen No.	1955-1965 Readings: 1395 Cycles 1955 %E	$\%V^2$	1562 Cycles 1956 %E	$\%V^2$	1706 Cycles 1957 %E	$\%V^2$	1777 Cycles 1958 %E	$\%V^2$	1927 Cycles 1959 %E	$\%V^2$	1998 Cycles 1960 %E	$\%V^2$	2139 Cycles 1961 %E	$\%V^2$	2228 Cycles 1962 %E	$\%V^2$	2334 Cycles 1963 %E	$\%V^2$	2469 Cycles 1964 %E	$\%V^2$	2632 Cycles 1965 %E	$\%V^2$
9C	A-49-E	140	99	141	96	184	94	149	99	133	90	130	95	136	96	130	96	130	93	124	87	118	--
	B-49-E	129	98	135	99	140	95	118	97	106	91	F											
	C-49-E	128	95	136	95	127	92	140	93	124	89	124	92	130	93	121	97	124	--	121	--	115	--
10C	A-50-E	152	98	155	99	153	96	168	99	150	95	150	97	154	97	147	102	147	98	144	97	141	100
	C-50-E	142	98	144	98	142	96	139	98	129	94	136	95	139	98	136	99	136	96	133	--	130	--
11C	A-51-E	130	98	134	99	135	94	145	101	129	94	123	95	126	95	123	100	120	101	117	92	120	94
	B-51-E	140	97	144	96	139	94	152	98	136	92	133	95	139	96	133	98	133	91	127	91	124	95
	C-51-E	137	95	144	97	140	93	150	98	139	92	134	95	141	96	138	98	135	98	129	--	126	--
12C	A-52-E	142	97	145	98	145	94	156	98	142	94	139	96	142	96	135	100	132	96	132	98	129	100
	B-52-E	152	99	155	101	154	97	165	100	154	96	150	98	154	98	147	100	147	99	147	95	143	99
	C-52-E	150	98	153	100	150	96	161	97	150	94	146	97	146	98	139	98	139	94	139	93	132	99
9D	A-53-E	143	96	147	98	148	95	155	98	138	92	135	95	145	98	135	101	135	93	128	91	125	97
	C-53-E	149	94	153	95	110	92	166	93	145	89	138	91	145	95	138	95	135	--	132	--	142	--
10D	A-54-E	149	95	154	97	157	92	172	97	153	92	149	95	149	95	145	98	145	88	141	98	138	94
	B-54-E	139	99	142	101	140	97	147	99	133	95	130	98	133	98	126	55	129	102	126	98	123	102
	C-54-E	143	96	147	98	145	92	145	95	138	90	135	93	135	96	132	83	129	95	126	97	120	100
11D	A-55-E	142	95	146	94	145	91	152	94	138	89	135	90	138	91	138	93	131	93	125	89	119	91
	B-55-F	129	98	131	98	125	96	119	99	125	93	122	96	122	97	119	100	116	97	107	--	107	--
	C-55-E	134	97	136	96	133	93	143	97	130	91	127	94	133	95	127	95	124	97	124	85	118	--
12D	A-56-E	152	98	155	98	159	96	163	100	152	95	148	96	156	97	145	92	145	99	141	--	137	--
	B-56-E	143	97	146	97	142	95	149	97	142	93	138	94	138	95	135	94	135	96	132	--	129	--
	C-56-E	141	96	145	96	142	95	153	97	142	92	139	95	139	97	136	95	136	101	133	95	130	--
9E	A-57-E	93	96	78	90	F																	
	B-57-E	112	--	95	--	F																	
	C-57-E	148	--	115	--	F																	
10E	A-58-E	137	98	143	98	142	95	145	100	142	96	139	97	142	96	139	--	139	--	136	--	133	--
	B-58-E	125	99	116	99	130	97	120	--	126	--	120	--	123	--	117	--	117	--	114	--	114	--
	C-58-E	133	97	138	92	152	95	163	97	152	94	152	95	135	97	152	59	156	--	156	--	152	--
11E	A-59-E	121	98	124	94	115	93	121	92	Broken in handling													
	B-59-E	134	98	144	97	115	91	141	--	122	--	111	--	F									
	C-59-E	116	--	109	--	105	--	113	--	85	--	71	--	F									
12E	A-60-E	130	99	133	99	131	96	141	97	127	93	127	98	127	99	120	57	117	--	117	--	123	--
	B-60-E	107	101	112	99	113	--	113	--	F													
	C-60-E	138	--	141	--	140	--	151	--	134	--	141	--	141	--	138	--	135	--	135	--	132	--

Mix No.	Specimen No.	1966 Readings: 2762 Cycles 1966 (Final) %E	$\%V^2$
3A	A-3-E	162	--
	B-3-E	141	84
	C-3-E	138	87
5A	C-5-E	132	--
6A	A-6-E	150	--
7A	A-7-E	170	89
	B-7-E	151	79
	C-7-E	152	86
8A	A-8-E	145	85
	B-8-E	176	--
	C-8-E	145	--

(Continued)

Table 1-VR (Continued)

Mix No.	Specimen No.	1966 Readings: 2762 Cycles 1966 (Final) %E	%V²
3B	B-11-E	162	--
	C-11-E	127	--
5B	A-13-E	138	--
	B-13-E	172	--
	C-13-E	153	--
7B	A-15-E	165	--
	B-15-E	160	--
	C-15-E	137	--
8B	A-16-E	127	--
	B-16-E	139	--
1C	C-17-E	155	--
3C	A-19-E	175	--
	B-19-E	152	--
	C-19-E	155	87
4C	A-20-E	152	--
	B-20-E	161	--
	C-20-E	163	--
5C	A-21-E	143	--
	B-21-E	152	--
6C	A-22-E	139	77
	B-22-E	168	--
	C-22-E	139	--
7C	A-23-E	166	--
	B-23-E	175	82
8C	A-24-E	166	84
	B-24-E	178	--
	C-24-E	175	84
3D	A-27-E	178	--
	B-27-E	181	--
	C-27-E	163	--
5D	A-29-E	141	--
	B-29-E	150	--
	C-29-E	163	--
6D	A-30-E	142	--
7D	A-31-E	188	--
	B-31-E	143	84
	C-31-E	163	--
8D	A-32-E	167	--
	B-32-E	148	--
	C-32-E	157	--
3E	A-35-E	218	--
	B-35-E	262	--
	C-35-E	212	--
4E	B-36-E	Failed	
5E	A-37-E	Failed	
7E	A-39-E	177	--
	B-39-E	139	84
	C-39-E	161	85
8E	A-40-E	211	--
	B-40-E	169	--
	C-40-E	174	--
9A	B-41-E	186	--
	C-41-E	99	--

(Continued)

Table 1-VR (Concluded)

		1966 Readings	
		2762 Cycles 1966 (Final)	
Mix No.	Specimen No.	%E	%V[2]
10A	A-42-E	151	85
	B-42-E	144	78
	C-42-E	137	--
11A	A-43-E	127	--
	B-43-E	143	81
12A	A-44-E	157	--
	B-44-E	141	81
	C-44-E	128	84
	D-44-E	162	87
9B	A-45-E	121	--
	B-45-E	117	--
	C-45-E	139	--
10B	A-46-E	160	83
	B-46-E	135	88
	C-46-E	137	89
	D-46-E	140	86
11B	A-47-E	132	--
	B-47-E	143	--
	C-47-E	123	84
12B	A-48-E	130	89
	C-48-E	148	--
9C	A-49-E	121	--
	C-49-E	124	--
10C	A-50-E	155	91
	C-50-E	137	--
11C	A-51-E	126	86
	B-51-E	136	84
	C-51-E	120	--
12C	A-52-E	132	83
	B-52-E	154	89
	C-52-E	132	88
9D	A-53-E	131	86
	C-53-E	149	--
10D	A-54-E	145	88
	B-54-E	123	87
	C-54-E	105	84
11D	A-55-E	128	79
	B-55-E	113	--
	C-55-E	127	--
12D	A-56-E	152	--
	B-56-E	132	--
	C-56-E	140	--
10E	A-58-E	140	--
	B-58-E	124	--
	C-58-E	159	--
12E	A-60-E	117	--
	C-60-E	146	--

Field and Laboratory Correlation Program*

Six coarse and eight fine aggregates were used in 48 combinations to make concrete specimens, all with the same water-cement ratio, air content, and slump, for comparative testing in accelerated freezing-and-thawing and exposure to natural weathering.

A total of 450 beams were fabricated, the characteristics of the concrete being: 2-1/2 ± 1/2 in. slump, air content of 4-1/2 ± 1/2%, water-cement ratio of 5.5 gal per bag, and sand content from 36 to 42% depending on particle shape. The cement factors ranged from 4.56 to 6.66 bags per cu yd. Six 3-1/2- by 4-1/2- by 16-in. beams and three 6- by 6- by 30-in. beams were made for each of the 48 combinations; also, two combinations were repeated, bringing the total number of beams to 450. Half the small beams (150) were tested in the laboratory, and half the small (150) and all of the large beams (150) were installed on the exposure rack at Treat Island in December 1948.

Tables 1-FLC and 2-FLC list the concrete specimens and give their exposure record along with their aggregates.

In May 1952, 41 of the small beams (3-1/2 by 4-1/2 by 16 in.) exposed at Treat Island were returned to the laboratory for tests. Thirty of these specimens were still sound and eleven had failed. These laboratory tests are summarized in the referenced paper.* The findings were:

> Comparison of laboratory and field results indicates that each aggregate combination behaves in an individual manner in each exposure, as influenced by differences in materials and in exposures. Prediction of behavior in one type of exposure from behavior in another cannot be made unless all the differences between the two can fully be evaluated, which is not yet possible.

The exposure of the small beams at Treat Island was concluded in

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* See Thomas B. Kennedy and Katharine Mather, "Correlation between laboratory accelerated freezing and thawing and weathering at Treat Island, Maine," Journal, Amer. Conc. Inst. Proceedings, vol 50 (October 1953).

1957 after 1108 cycles of freezing-and-thawing (9 winters). The exposure of the large beams was discontinued in 1967 after 2320 cycles of freezing-and-thawing (19 winters). Final determinations of %E and $\%V^2$ were made in 1966 after 18 winters (2164 cycles of freezing-and-thawing). In 1967 only five large beams remained; three of these beams were made using limestone as the fine aggregate and crushed chert as the coarse aggregate.

Findings

If the exposure record of both the small and the large beams are considered the findings are:

a. The most durable aggregate combination was a mixture using crushed chert both as a fine and coarse aggregate.

b. The least durable aggregate combinations was a mixture using a natural nonchert sand and quartzite.

c. The order of durability of coarse aggregates, from most durable to least durable, was: Crushed chert gravel, limestone, granite, uncrushed chert gravel, nonchert gravel, and quartzite.

d. The order of durability of fine aggregates, from most durable to least durable was:

Quartzite
Crushed chert sand
Granite
Natural siliceous sand, limestone, and river sand (essentially equal in durability)
Natural chert sand
Natural nonchert sand

(Issued Sept 1967) Program 15

Table 1-FLC

Record of Testing of Small Concrete Beams, Field and Laboratory Correlation Program

1948-1957 (Installed December 1948)

Beam No.	Fine Aggregate	Coarse Aggregate	1948-1957 Readings: 0 Cycles 1948 %E	105 Cycles 1949 %E	266 Cycles 1950 %E	355 Cycles 1951 %E	456 Cycles 1952 %E	541 Cycles 1953 %E	652 Cycles 1954 %E	797 Cycles 1955 %E	964 Cycles 1956 %E	1108 Cycles 1957 (Final) %E
2983	Limestone	Limestone	100	100	97	91	69*					
2984			100	101	99	92	73	66	50F**			
2985			100	101	103	104	64	50F				
3443	Limestone	Limestone	100	103	102	98	102*					
3444	(rerun)		100	105	96	89	84	52	50F			
3445			100	103	93	89	61	81	77	66	61	37F
2965	Granite	Limestone	100	101	102	102	102*					
2966			100	101	101	98	96	88	82	74	81	50F
2967			100	100	102	101	100	97	89	80	81	29F
3229	River	Limestone	100	101	91	80	63*					
3230	sand		100	99	92	79	63	55	36F			
3231			100	98	90	81	70	53	37F			
3220	Nonchert	Limestone	100	103	89	82	64*					
3221	sand		100	97	83	74	58	36F				
3222			100	100	94	91	77	72	48F			
2992	Natural	Limestone	100	100	103	102	98*					
2993	siliceous		100	102	99	97	91	86	76	70	75	27F
2994			100	99	98	93	81	77	64	47F		
3202	Crushed	Limestone	100	100	97	92	86*					
3203	chert		100	94	96	97	85	87	78	87	87	50F
3204			100	99	98	96	90	87	84	92	82	50F
2977	Quartzite	Limestone	100	102	99	99	93*					
2978			100	99	98	96	87	83	73	63	40F	
2979			100	100	100	93	90	84	82	73	80	37F
3211	Natural	Limestone	100	99	96	89	77*					
3212	chert		100	99	93	85	74	64	51	32F		
3213			100	101	93	96	73	60	41F			
3028	Limestone	Granite	100	101	99	59	33F					
3029			100	102	105	94	40F					
3030			100	102	104	95	40F					
3001	Granite	Granite	100	102	110	115	119*					
3002			100	103	113	117	120	118	82	73	70†	
3003			100	104	111	114	108	89	61	35F		
3265	River	Granite	100	103	104	89	48F					
3266	sand		100	103	103	82	45F					
3267			100	104	103	93	48F					
3256	Nonchert	Granite	100	103	108	105	72*					
3257	sand		100	102	104	90	47F					
3258			100	103	107	107	78	50F				
3019	Natural	Granite	100	103	106	105	49F					
3020	siliceous		100	103	107	104	74	39F				
3021			100	105	107	106	64	32F				
3238	Crushed	Granite	100	106	112	112	104*					
3239	chert		100	107	111	110	95	80	53	44F		
3240			100	103	109	110	86	71	43F			
3010	Quartzite	Granite	100	102	111	115	115*					
3011			100	101	107	111	107	100	98	30F		
3012			100	103	110	120	122	122	107*			
3247	Natural	Granite	100	102	106	104	56*					
3248	chert		100	101	104	102	51	28F				
3249			100	103	107	108	63	28F				
3082	Limestone	Nonchert	100	99	Disintegrated							
3083		gravel	100	94	Disintegrated							
3084			100	98	Disintegrated							

(Continued)

Note: None of these small beams remained under test after 1957.
* Returned to laboratory.
** F denotes specimen has failed.
† Broken in handling.

(Sheet 1)

Table 1-FLC (Continued)

			1948-1957 Readings									
Beam No.	Fine Aggregate	Coarse Aggregate	0 Cycles 1948 %E	105 Cycles 1949 %E	266 Cycles 1950 %E	355 Cycles 1951 %E	456 Cycles 1952 %E	541 Cycles 1953 %E	652 Cycles 1954 %E	797 Cycles 1955 %E	964 Cycles 1956 %E	1108 Cycles 1957 (Final) %E
3100	Granite	Nonchert	100	103	93	76	46F					
3101		gravel	100	102	98	82	49F					
3102			100	103	97	76	46F					
3337	River	Nonchert	100	98	96	85	45F					
3338	sand	gravel	100	98	87	46F						
3339			100	98	76	41F						
3310	Nonchert	Nonchert	100	96	82	30F						
3311	sand	gravel	100	99	91	41F						
3312			100	96	86	41F						
3091	Natural	Nonchert	100	103	91	71	49F					
3092	siliceous	gravel	100	102	88	60	49F					
3093			100	101	83	41F						
3301	Crushed	Nonchert	100	99	89	61	41F					
3302	chert	gravel	100	96	91	71	47F					
3303			100	97	88	61	41F					
3073	Quartzite	Nonchert	100	99	95	91	51*					
3074		gravel	100	98	96	95	44F					
3075			100	96	97	91	50F					
3328	Natural	Nonchert	100	96	89	52	35F					
3329	chert	gravel	100	101	92	68	41F					
3330			100	97	96	41F						
3139	Limestone	Uncrushed	100	102	71	42F						
3140		chert	100	101	97	34F						
3141			100	103	92	50F						
3112	Granite	Uncrushed	100	100	99	85	58*					
3113		chert	100	101	102	101	82	51	34F			
3114			100	101	103	102	94	66	44F			
3355	River	Uncrushed	100	97	93	87	65*					
3356	sand	chert	100	97	88	62	55	50F				
3357			100	98	96	92	44F					
3364	Nonchert	Uncrushed	100	98	94	77	65*					
3365	sand	chert	100	99	97	90	45F					
3366			100	97	98	86	48F					
3130	Natural	Uncrushed	100	99	99	103	57*					
3131	siliceous	chert	100	102	99	101	70	34F				
3132			100	101	101	105	58	56	37F			
3375	Crushed	Uncrushed	100	99	82	73	47F					
3376	chert	chert	100	98	97	73	62	59	24F			
3377			100	103	104	104	76	81	47F			
3121	Quartzite	Uncrushed	100	103	100	96	93*					
3122		chert	100	101	97	93	92	62	41F			
3123			100	101	98	96	94	64	42F			
3346	Natural	Uncrushed	100	98	92	85	58*					
3347	chert	chert	100	96	90	78	59	27F				
3348			100	97	95	94	49F					
3148	Limestone	Crushed	100	102	104	100	68*					
3149		chert	100	102	104	101	91	50F				
3150			100	102	101	98	96	82	90	50F		
3157	Granite	Crushed	100	105	106	107	105*					
3158		chert	100	104	103	105	103	103	54	33F		
3159			100	104	104	103	99	95	61	43F		
3411	River	Crushed	100	105	106	105	103*					
3412	sand	chert	100	102	105	105	105	102	101	90	85	43F
3413			100	106	106	108	101	107	107	97	79	44F
3402	Nonchert	Crushed	100	103	105	106	106*					
3403	sand	chert	100	103	105	105	105	98	95	60	42F	
3404			100	103	106	105	100	102	100	71	79	30F

(Continued)

* Returned to laboratory.

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Table 1-FLC (Concluded)

Program 15

			1948-1957 Readings									
Beam No.	Fine Aggregate	Coarse Aggregate	0 Cycles 1948 %E	105 Cycles 1949 %E	266 Cycles 1950 %E	355 Cycles 1951 %E	456 Cycles 1952 %E	541 Cycles 1953 %E	652 Cycles 1954 %E	797 Cycles 1955 %E	964 Cycles 1956 %E	1108 Cycles 1957 (Final) %E
3175	Natural	Crushed	100	101	102	103	101*					
3176	siliceous	chert	100	101	102	102	101	101	95	63	63	50F
3177			100	100	101	102	99	101	92	49F		
3384	Crushed	Crushed	100	103	106	108	97*					
3385	chert	chert	100	104	107	108	108	108	106	97	85	50F
3386			100	104	105	106	Lost					
3166	Quartzite	Crushed	100	100	102	101	97*					
3167		chert	100	102	102	101	96	98	95	80	81	34F
3168			100	102	101	101	99	99	94	73	77	50F
3393	Natural	Crushed	100	104	102	102	Lost					
3394	chert	chert	100	102	101	101	101*					
3395			100	103	102	102	96	102	101	87	77	29F
3055	Limestone	Quartzite	100	100	85	39F						
3056			100	99	42F							
3057			100	103	97	44F						
3037	Granite	Quartzite	100	102	101	81	42F					
3038			100	99	92	62	39F					
3039			100	101	102	92	46F					
3292	River	Quartzite	100	101	72	42F						
3293	sand		100	100	85	41F						
3294			100	99	78	38F						
3319	Nonchert	Quartzite	100	97	61	49F						
3320	sand		100	99	48F							
3321			100	96	66	50F						
3046	Natural	Quartzite	100	100	75	46F						
3047	siliceous		100	100	94	42F						
3048			100	99	84	41F						
3283	Crushed	Quartzite	100	99	100	97	60	50F				
3284	chert		100	102	102	91	49F					
3285			100	97	86	67	40F					
3064	Quartzite	Quartzite	100	101	77	39F						
3065			100	101	94	80	43F					
3066			100	98	77	42F						
3428	Quartzite	Quartzite	100	107	112	102	95*					
3429	(rerun)		100	105	110	92	82	53	52	40F		
3430			100	107	112	96	70	61	56	50F		
3274	Natural	Quartzite	100	100	37F							
3275	chert		100	104	38F							
3276			100	101	38F							

* Returned to laboratory.

(Issued Sept 1967)

Table 2-FLC

Program 15

Record of Testing of Large Concrete Beams, Field and Laboratory Correlation Program

1948-1966 (Installed December 1948)

			1948-1955 Readings											
			0 Cycles 1948	105 Cycles 1949	266 Cycles 1950	355 Cycles 1951	456 Cycles 1952	541 Cycles, 1953			652 Cycles 1954		797 Cycles 1955	
Beam No.	Fine Aggregate	Coarse Aggregate	%E	%E	%E	%E	%E	%E	Pulse Veloc fps	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$
2971	Quartzite	Limestone	100	104	107	102	90	78	14,705	100	65	83	50F	
2972			100	108	111	111	108	92	14,970	100	77	88	47F	
2973			100	105	109	109	109	101	15,335	100	86	92	67	86
2986	Limestone	Limestone	100	102	106	106	100	83	14,795	100	62	76	50F	
2987			100	99	108	107	106	84	14,705	100	71	87	44F	
2988			100	107	111	111	111	115	14,620	100	108	101	100	99
2968	Granite	Limestone	100	102	105	106	106	101	15,245	100	84	85	69	76
2969			100	105	109	109	103	99	15,060	100	78	86	65	81
2970			100	104	108	106	105	77	14,975	100	71	84	59	75
3232	River sand	Limestone	100	104	101	83	83	56	------	---	50F*			
3233			100	96	91	66	53	17F						
3234			100	102	101	88	70	52	13,890	100	50F			
3223	Nonchert sand	Limestone	100	101	102	96	80	66	------	---	50F			
3224			100	98	99	87	78	65	------	---	50F			
3225			100	104	98	100	80	68	------	---	49F			
2989	Natural siliceous	Limestone	100	104	106	80	64	46F						
2990			100	102	103	91	66	50F						
2991			100	98	96	99	63	53	13,515	100	50F			
3205	Crushed chert	Limestone	100	100	104	103	104	99	15,430	100	80	82	64	78
3206			100	101	104	102	93	77	15,150	100	58	83	50F	
3207			100	99	102	95	81	68	14,285	100	55	78	50F	
3214	Natural chert	Limestone	100	99	101	97	86	76	15,245	100	66	80	59	79
3215			100	102	100	82	69	50F						
3216			100	101	103	97	74	56	14,970	100	50F			
3004	Granite	Granite	100	106	115	118	122	121	15,060	100	124	100	115	99
3005			100	103	112	116	118	116	15,060	100	98	98	72	95
3006			100	104	112	116	118	122	15,150	100	115	98	94	94
3013	Quartzite	Granite	100	97	105	110	114	119	15,245	100	121	101	119	99
3014			100	107	113	118	120	120	15,150	100	98	96	73	95
3015			100	105	112	117	118	111	15,245	100	85	96	53	95
3031	Limestone	Granite	100	105	113	117	120	123	14,795	100	100	100	100	102
3032			100	103	114	115	118	119	14,705	100	96	100	96	92
3033			100	106	114	119	121	110	14,795	100	75	98	43F	
3268	River sand	Granite	100	108	115	113	88	35F						
3269			100	102	121	125	126	98	Broken in handling					
3270			100	107	111	104	74	33F						
3259	Nonchert sand	Granite	100	107	114	116	105	50F						
3260			100	109	119	117	104	51	------	---	50F			
3261			100	107	114	115	106	45F						
3022	Natural siliceous	Granite	100	108	115	119	121	110	14,970	100	60	95	50F	
3023			100	108	114	114	58	50F						
3024			100	109	116	117	91	50F						
3241	Crushed chert	Granite	100	103	111	112	115	100	15,530	100	56	81	50F	
3242			100	102	112	114	119	121	16,130	100	108	88	59	79
3243			100	107	117	120	125	128	15,825	100	123	91	86	84
3250	Natural chert	Granite	100	107	112	113	100	44F						
3251			100	108	114	110	70	25F						
3252			100	105	113	113	73	50F						
3067	Quartzite	Quartzite	100	103	106	100	54	50F						
3068			100	96	99	98	97	90	14,970	100	75	94	59	87
3069			100	100	103	100	67	27F						
3431	Quartzite (rerun)	Quartzite	100	107	112	104	90	70	15,430	100	48F			
3432			100	105	111	104	90	66	15,530	100	46F			
3433			100	107	112	101	87	67	15,430	100	47F			

(Continued)

* F denotes specimen has failed.

(Issued Sept 1967)

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Table 2-FLC (Continued)

			1948-1955 Readings											
			0 Cycles 1948	105 Cycles 1949	266 Cycles 1950	355 Cycles 1951	456 Cycles 1952	541 Cycles, 1953			652 Cycles 1954		797 Cycles 1955	
Beam No.	Fine Aggregate	Coarse Aggregate	%E	%E	%E	%E	%E	%E	Pulse Veloc fps	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$
3058	Limestone	Quartzite	100	102	104	82	40F							
3059			100	103	85	66	33F							
3060			100	105	108	79	40F							
3040	Granite	Quartzite	100	100	98	74	42F							
3041			100	102	102	101	43F							
3042			100	101	101	93	52	30F						
3295	River sand	Quartzite	100	100	97	44F								
3296			100	102	97	44F								
3297			100	96	91	44F								
3322	Nonchert sand	Quartzite	100	101	48F									
3323			100	100	27F									
3324			100	102	25F									
3049	Natural siliceous	Quartzite	100	102	102	98	44F							
3050			100	100	102	96	44F							
3051			100	101	100	57	44F							
3286	Crushed chert	Quartzite	100	101	104	92	59	20F						
3287			100	100	102	84	34F							
3288			100	101	105	102	63	19F						
3277	Natural chert	Quartzite	100	101	96	58	41F							
3278			100	103	99	61	47F							
3279			100	103	101	62	47F							
3115	Granite	Uncrushed chert	100	98	102	103	102	96	14,535	100	83	94	76	90
3116			100	103	106	103	92	61	14,045	100	40F			
3117			100	106	108	105	80	50F						
3142	Limestone	Uncrushed chert	100	103	104	97	48F							
3143			100	98	98	86	52	50F						
3144			100	98	101	100	93	76	14,370	100	69	88	57	93
3358	River sand	Uncrushed chert	100	101	105	104	104	81	15,245	100	41F			
3359			100	102	105	101	79	40F						
3360			100	103	104	92	53	50F						
3367	Nonchert sand	Uncrushed chert	100	104	108	103	74	50F						
3368			100	102	106	102	93	43F						
3369			100	102	104	87	42F							
3133	Natural siliceous	Uncrushed chert	100	95	96	96	61	50F						
3134			100	100	99	88	50F							
3135			100	99	95	69	42F							
3378	Crushed chert	Uncrushed chert	100	102	105	99	89	59	14,535	100	37F			
3379			100	99	100	100	96	78	14,970	100	44F			
3380			100	101	101	96	73	37F						
3124	Quartzite	Uncrushed chert	100	97	98	98	92	77	15,060	100	52	86	45F	
3125			100	95	98	97	98	95	15,530	100	73	86	49F	
3126			100	97	101	100	100	98	15,150	100	68	86	46F	
3349	Natural chert	Uncrushed chert	100	100	97	74	46F							
3350			100	100	101	77	43F							
3351			100	103	105	99	52	50F						
3151	Limestone	Crushed chert	100	101	106	105	108	110	15,060	100	108	89	102	91
3152			100	102	107	106	109	109	14,975	100	109	92	107	94
3153			100	98	106	107	110	111	14,450	100	114	93	110	98
3160	Granite	Crushed chert	100	104	109	96	112	112	15,060	100	114	92	108	92
3161			100	102	106	107	110	111	15,060	100	112	93	110	93
3162			100	98	104	104	106	107	15,060	100	101	91	92	88
3169	Quartzite	Crushed chert	100	100	104	104	107	109	15,150	100	109	93	108	95
3170			100	100	103	103	106	106	15,430	100	108	90	103	90
3171			100	100	104	104	107	110	15,335	100	109	90	103	92
3387	Crushed chert	Crushed chert	100	104	99	99	116	118	15,060	100	119	90	119	91
3388			100	103	111	111	114	116	15,060	100	117	89	115	93
3389			100	101	107	109	112	114	15,150	100	116	91	116	94
3396	Natural chert	Crushed chert	100	103	109	108	113	113	15,530	100	114	88	113	92
3397			100	103	107	107	112	113	15,530	100	114	90	113	94
3398			100	104	110	110	115	115	15,825	100	116	88	116	93

(Continued)

Table 2-FLC (Continued)

Beam No.	Fine Aggregate	Coarse Aggregate	1948-1955 Readings: 0 Cycles 1948 %E	105 Cycles 1949 %E	266 Cycles 1950 %E	355 Cycles 1951 %E	456 Cycles 1952 %E	541 Cycles, 1953 %E	541 Cycles, 1953 Pulse Veloc fps	541 Cycles, 1953 %V^2	652 Cycles 1954 %E	652 Cycles 1954 %V^2	797 Cycles 1955 %E	797 Cycles 1955 %V^2
3405	Nonchert	Crushed	100	116	121	119	119	104	15,335	100	100	89	73	81
3406	sand	chert	100	105	112	112	117	117	15,530	100	119	90	119	88
3407			100	106	114	114	118	120	Broken in handling					
3414	River	Crushed	100	105	111	111	115	111	15,150	100	115	92	109	93
3415	sand	chert	100	105	110	111	123	123	15,430	100	118	91	123	91
3416			100	108	114	114	119	114	15,430	100	119	89	119	92
3178	Natural	Crushed	100	101	104	103	107	109	15,335	100	105	90	66	87
3179	siliceous	chert	100	101	103	103	107	109	15,430	100	105	91	77	88
3180			100	98	99	100	103	105	15,245	100	101	94	64	90
3085	Limestone	Nonchert	100	103	80	50F								
3086		gravel	100	100	85	50F								
3087			100	104	97	50F								
3103	Granite	Nonchert	100	102	103	63	47F							
3104		gravel	100	103	105	93	49F							
3105			100	108	109	102	51	25F						
3340	River	Nonchert	100	99	101	88	46F							
3341	sand	gravel	100	103	105	90	49F							
3342			100	100	98	53	36F							
3313	Nonchert	Nonchert	100	101	91	34F								
3314	sand	gravel	100	96	89	38F								
3315			100	100	94	41F								
3094	Natural	Nonchert	100	105	104	84	45F							
3095	siliceous	gravel	100	102	102	65	41F							
3096			100	104	105	102	48F							
3304	Crushed	Nonchert	100	103	105	93	56	27F						
3305	chert	gravel	100	102	102	90	50F							
3306			100	104	112	99	60	32F						
3076	Quartzite	Nonchert	100	104	106	106	92	50F						
3077		gravel	100	104	104	103	82	50F						
3078			100	98	101	100	100	84	15,150	100	55	92	41F	
3331	Natural	Nonchert	100	102	100	84	50F							
3332	chert	gravel	100	108	108	78	50F							
3333			100	105	92	45F								
3446	Limestone	Limestone	100	107	114	112	117	110	15,625	100	101	80	95	77
3447	(rerun)		100	102	108	106	101	94	15,150	100	80	80	72	75
3448			100	107	113	111	102	92	15,335	100	76	78	71	74

Beam No.	Fine Aggregate	Coarse Aggregate	1956-1963 Readings: 964 Cycles 1956 %E	964 Cycles 1956 %V^2	1108 Cycles 1957 %E	1108 Cycles 1957 %V^2	1179 Cycles 1958 %E	1179 Cycles 1958 %V^2	1329 Cycles 1959 %E	1329 Cycles 1959 %V^2	1400 Cycles 1960 %E	1400 Cycles 1960 %V^2	1541 Cycles 1961 %E	1541 Cycles 1961 %V^2	. 1630 Cycles 1962 %E	1630 Cycles 1962 %V^2	1736 Cycles 1963 %E	1736 Cycles 1963 %V^2
2973	Quartzite	Limestone	62	83	62	69	50F											
2988	Limestone	Limestone	101	98	89	94	86	98	76	87	F							
2968	Granite	Limestone	65	61	42F													
2969			71	73	50F													
2970			50F															
3205	Crushed chert	Limestone	54	68	50F													
3214	Natural chert	Limestone	59	86	41F													
3004	Granite	Granite	100	94	82	85	99	88	54	49	F							
3005			59	89	59	---	50F											
3006			59	86	42F													
3013	Quartzite	Granite	126	100	126	99	126	105	122	95	80	93	82	91	74	93	70	95
3014			53	90	44F													
3015			37F															

(Continued)

(Issued Sept 1967)

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Table 2-FLC (Concluded)

Beam No.	Fine Aggregate	Coarse Aggregate	964 Cycles 1956 %E	964 Cycles 1956 $\%V^2$	1108 Cycles 1957 %E	1108 Cycles 1957 $\%V^2$	1179 Cycles 1958 %E	1179 Cycles 1958 $\%V^2$	1329 Cycles 1959 %E	1329 Cycles 1959 $\%V^2$	1400 Cycles 1960 %E	1400 Cycles 1960 $\%V^2$	1541 Cycles 1961 %E	1541 Cycles 1961 $\%V^2$	1630 Cycles 1962 %E	1630 Cycles 1962 $\%V^2$	1736 Cycles 1963 %E	1736 Cycles 1963 $\%V^2$
			1956-1963 Readings															
3031	Limestone	Granite	120	104	98	98	91	105	94	98	125	103	120	99	114	106	119	106
3032			96	--	50F													
3242	Crushed	Granite	59	70	50F													
3243	chert		56	73	50F													
3068	Quartzite	Quartzite	55	85	55	72	50F											
3115	Granite	Uncrushed chert	75	93	71	82	60	87	57	79	55	64	56	81	52	85	46F	82
3144	Limestone	Uncrushed chert	50F															
3151	Limestone	Crushed	110	90	110	88	85	92	84	83	89	87	84	83	80	91	76	87
3152		chert	107	90	107	90	92	94	92	90	90	92	86	85	82	91	80	90
3153			112	97	112	91	96	97	96	92	99	93	92	90	86	93	92	98
3160	Granite	Crushed	107	90	103	83	74	88	62	66	57	71	55	68	50F	66		
3161		chert	110	91	110	86	93	93	86	81	83	83	78	72	72	86	68	81
3162			92	88	89	84	74	89	66	73	65	80	62	72	56	81	54	75
3169	Quartzite	Crushed	103	91	103	85	62	83	54	60	F							
3170		chert	102	88	97	81	66	80	70	53	F							
3171			93	86	77	81	115	83	96	65	96	64	Broken in handling					
3387	Crushed	Crushed	121	93	116	90	102	93	66	77	57	76	47F					
3388	chert	chert	122	91	117	87	113	93	86	80	64	81	58	71	41F	--		
3389			119	91	114	88	114	94	95	83	74	71	68	80	51	81	NR**	80
3396	Natural	Crushed	113	88	66	82	83	71	F									
3397	chert	chert	109	87	53	73	45F											
3398			117	87	90	84	66	79	F									
3405	Nonchert	Crushed	69	78	50F													
3406	sand	chert	122	85	120	83	129	86	63	67	F							
3414	River	Crushed	111	89	106	88	101	88	81	76	65	80	54	74	39F	65		
3415	sand	chert	125	86	116	86	114	89	79	73	62	77	45F					
3416			122	87	117	88	117	94	74	79	62	81	50F					
3178	Natural	Crushed	66	74	50F													
3179	siliceous	chert	77	71	50F													
3180			64	69	50F													
3446	Limestone	Limestone	95	76	87	65	92	72	82	57	78	70	70	--	F	--		
3447	(rerun)		50F															
3448			55	46	50F													

Beam No.	Fine Aggregate	Coarse Aggregate	1871 Cycles 1964 %E	1871 Cycles 1964 $\%V^2$	2034 Cycles 1965 %E	2034 Cycles 1965 $\%V^2$	2164 Cycles 1966 (Final) %E	2164 Cycles 1966 (Final) $\%V^2$
			1964- Readings					
3013	Quartzite	Granite	51	--	53	--	42F	
3031	Limestone	Granite	113	94	106	110	118	94
3151	Limestone	Crushed	60	83	69	98	65	--
3152		chert	71	81	73	94	64	79
3153			88	87	81	105	86	90
3161	Granite	Crushed	65	74	67	82	55	63
3162		chert	49F					
3389	Crushed chert	Crushed chert	45F					

** NR denotes a satisfactory reading was not obtained.

AD-A075 360 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS F/G 11/2
INVESTIGATION OF PERFORMANCE OF CONCRETE AND CONCRETING MATERIA--ETC(U)
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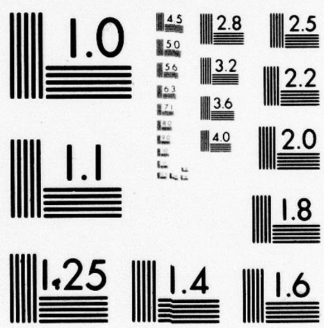

MICROCOPY RESOLUTION TEST CHART

Form Lining Investigation

In June 1946, 68 concrete specimens were installed on the Treat Island exposure rack. The purpose of this installation was to determine the influence of the use of absorptive form lining on the durability of mass concrete made with and without air-entraining admixtures. The specimens consisted of concrete cores (6 in. in diameter by 8 in.) encased in a 2-in. thickness of mortar on all but the formed surface. These cores were diamond-drilled from 10-cu-ft mass concrete blocks representing concrete of 3-1/2- and 4-bags-per-cu-yd cement factor with and without two air-entraining admixtures, with 4-in. traprock coarse aggregate, and with surfaces formed against either oiled wood forms or absorptive form lining.

Table 1-FL lists these specimens, and gives the degree or percentage of the formed surface deterioration along with other pertinent information.

The exposure was terminated in 1966 after 2413 cycles of freezing-and-thawing (20 winters); only two specimens survived the exposure.

Findings

The findings in this program are:

a. The order of durability of the 3-1/2-bag mixtures was as follows (most durable to least durable):

(1) Mixture containing resin soap.

(2) Mixture containing admixture X.

(3) Mixture with no air-entraining admixture.

b. The order of durability of the 4-bag mixtures was as follows (most durable to least durable):

(1) Mixture containing admixture X.

(2) Mixture containing resin soap.

(3) Mixture containing no air-entraining admixture.

c. The surfaces formed against absorptive form lining had greater durability than surfaces formed against oiled wood with all mixtures except the 4-bag mixture containing resin soap. With this mixture, the surfaces formed against the oiled wood had greater durability.

(Issued Sept 1967)

Table 1-FL

Program 16

Record of Formed Surface Deterioration, Degree of Percent, Form Lining Investigation

1946-1966 (Installed June 1946)

Core No.	Form Lining	Air-entraining Admixture	Cement Factor bags/cu yd	1946-1958 Readings: 0 Cycles 1946	249 Cycles 1948	515 Cycles 1950	604 Cycles 1951	705 Cycles 1952	790 Cycles 1953	901 Cycles 1954	1046 Cycles 1955	1213 Cycles 1956	1357 Cycles 1957	1428 Cycles 1958
25-1P	Wood	None	3.5	0	M*	40	40	60	60	70	70	80	100F**	
25-3P	Wood			0	0	S	5	10	10	12	15	25	25	30
25-1C	Absorptive			0	0	0	0	0	10	80	80	80	80	80
25-3C	Absorptive			0	0	0	1	10	25	90	90	90	90	100F
58-1P	Wood	None	3.5	0	H*	70	100F							
58-2P	Wood			0	H	90	100F							
58-3P	Wood			0	H	100F								
58-1C	Absorptive			0	0	H	50	50	50	60	60	60	60	70
58-2C	Absorptive			0	0	0	0	10	20	60	60	60	60	60
58-3C	Absorptive			0	0	T*	T	2	10	40	70	80	90	90
27-1P	Wood	None	4.0	0	S*	S	15	15	15	15	30	50	80	80
27-2P	Wood			0	T	S	10	25	25	25	90	100F		
27-3P	Wood			0	M	30	75	85	100F					
27-1C	Absorptive			0	0	0	2	5	5	15	75	100F		
27-2C	Absorptive			0	0	0	0	0	0	20	20	30	100F	
27-3C	Absorptive			0	0	0	1	1	1	1	5	10	10	50
61-1P	Wood	None	4.0	0	S	20	80	90	95	100F				
61-2P	Wood			0	S	M	40	40	40	60	70	100F		
61-3P	Wood			0	S	20	40	90	90	100F				
61-1C	Absorptive			0	0	S	S	20	20	40	60	60	60	70
61-2C	Absorptive			0	0	0	5	5	5	10	10	20	50	50
61-3C	Absorptive			0	0	S	2	10	20	40	70	70	100F	
28-1P	Wood	Resin	4.0	0	0	20	40	40	40	50	50	50	50	50
28-2P	Wood	soap		0	S	30	40	60	75	85	100F			
28-3P	Wood			0	S	M	40	40	75	75	75	75	75	75
28-1C	Absorptive			0	S	M	20	20	20	30	50	50	100F	
28-2C	Absorptive			0	0	M	30	30	30	50	60	75	80	80
28-3C	Absorptive			0	0	M	30	30	50	90	90	100F		
62-1P	Wood	Resin	4.0	0	S	S	15	15	15	15	15	15	15	15
62-2P	Wood	soap		0	S	S	5	10	10	10	10	10	10	10
62-3P	Wood			0	T	T	5	5	10	10	10	10	10	10
62-1C	Absorptive			0	0	0	0	5	10	10	40	60	60	70
62-2C	Absorptive			0	S	M	25	50	70	70	70	80	80	80
62-3C	Absorptive			0	0	0	5	5	20	25	60	60	60	60
44-1P	Wood	Resin	3.5	0	S	M	40	40	40	50	50	80	80	100F
44-3P	Wood	soap		0	M	20	50	50	50	80	100F			
44-1C	Absorptive			0	M	20	20	30	40	70	80	80	80	100F
44-2C	Absorptive			0	0	T	3	10	10	30	50	75	80	90
44-3C	Absorptive			0	0	0	5	5	20	30	70	70	70	70
59-1P	Wood	Resin	3.5	0	M	50	95	95	95	95	95	95	100F	
59-2P	Wood	soap		0	M	20	60	70	80	80	80	80	90	90
59-3P	Wood			0	S	S	S	10	20	40	40	40	70	70
59-1C	Absorptive			0	S	S	S	5	5	5	10	40	70	70
59-2C	Absorptive			0	M	M	30	75	90	90	90	90	90	90
59-3C	Absorptive			0	T	T	S	1	10	10	40	40	60	80
32-1P	Wood	Admixture	3.5	0	H	50	50	60	60	60	60	60	60	60
32-2P	Wood	X		0	S	M	30	30	30	40	50	50	60	70
32-3P	Wood			0	S	M	30	40	40	40	40	50	60	60
32-1C	Absorptive			0	0	S	10	20	20	30	100F			
32-2C	Absorptive			0	0	0	0	10	10	10	20	30	50	60
32-3C	Absorptive			0	0	0	2	20	20	30	60	65	65	65
60-1P	Wood	Admixture	3.5	0	M	50	100F							
60-2P	Wood	X		0	0	90	100F							
60-3P	Wood			0	S	S	10	50	75	100F				
60-1C	Absorptive			0	0	0	2	2	2	10	15	50	50	50
60-2C	Absorptive			0	0	0	3	15	20	25	25	50	60	60
60-3C	Absorptive			0	H	H	35	35	35	70	90	90	100F	
33-1P	Wood	Admixture	4.0	0	S	S	15	25	25	60	60	60	60	60
33-2P	Wood	X		0	S	M	20	40	40	75	75	80	80	80
33-3P	Wood			0	0	S	15	40	45	50	50	50	60	80
33-1C	Absorptive			0	S	S	20	25	25	30	30	30	50	50
33-3C	Absorptive			0	0	M	20	20	20	20	40	40	50	70

(Continued)

* T = trace, S = slight, M = moderate, H = heavy; quantitative estimates of percentage of formed surface deterioration were not made on all specimens prior to 1952.

** Specimens with 100 percent of their formed surface deteriorated are considered to have failed, denoted by F.

(Issued Sept 1967)

Program 16

Table 1-FL (Concluded)

Core No.	Form Lining	Air Entrain-ing Admixture	Cement Factor bags/cu yd	1946-1958 Readings: 0 Cycles 1946	249 Cycles 1948	515 Cycles 1950	604 Cycles 1951	705 Cycles 1952	790 Cycles 1953	901 Cycles 1954	1046 Cycles 1955	1213 Cycles 1956	1357 Cycles 1957	1428 Cycles 1958
63-1P	Wood	Admixture	4.0	0	M	100F								
63-2P	Wood	X		0	H	H	65	90	90	100F				
63-3P	Wood			0	M	100F								
63-1C	Absorptive			0	0	T	2	35	40	60	70	80	80	80
63-2C	Absorptive			0	0	30	50	70	70	70	70	100F		
63-3C	Absorptive			0	M	M	20	30	30	30	40	60	60	60

Core No.	Form Lining	Air Entrain-ing Admixture	Cement Factor bags/cu yd	1959-1966 Readings: 1578 Cycles 1959	1649 Cycles 1960	1790 Cycles 1961	1879 Cycles 1962	1985 Cycles 1963	2120 Cycles 1964	2283 Cycles 1965	2413 Cycles 1966 (Final)
25-3P	Wood	None	3.5	30	30	40	100F				
25-1C	Absorptive			80	80	100F					
58-1C	Absorptive	None	3.5	70	70	70	70	100F			
58-2C	Absorptive			90	90	90	100F				
58-3C	Absorptive			100F							
27-1P	Wood	None	4.0	90	100F						
27-3C	Absorptive			100F							
61-1C	Absorptive	None	4.0	100F							
61-2C	Absorptive			70	70	100F					
28-1P	Wood	Resin	4.0	60	60	80	90	100F			
28-3P	Wood	soap		75	100F						
28-2C	Absorptive			100F							
62-1P	Wood	Resin	4.0	35	35	50	70	100F			
62-2P	Wood	soap		20	20	20	30	30	30	30	100F
62-3P	Wood			20	20	20	30	50	50	70	100F
62-1C	Absorptive			70	70	70	70	100F			
62-2C	Absorptive			100F							
62-3C	Absorptive			90	90	100F					
44-2C	Absorptive	Resin	3.5	90	90	100F					
44-3C	Absorptive	soap		70	70	70	80	100F			
59-2P	Wood	Resin	3.5	100F							
59-3P	Wood	soap		90	90	90	90	100F			
59-1C	Absorptive			70	70	70	100F				
59-2C	Absorptive			90	100F						
59-3C	Absorptive			80	80	80	80	100F			
32-1P	Wood	Admixture	3.5	70	70	70	100F				
32-2P	Wood	X		80	80	100F					
32-3P	Wood			75	90	90	100F				
32-2C	Absorptive			70	70	80	80	100F			
32-3C	Absorptive			65	70	70	100F				
60-1C	Absorptive	Admixture	3.5	70	70	80	100F				
60-2C	Absorptive	X		60	70	100F					
33-1P	Wood	Admixture	4.0	60	60	60	80	100F			
33-2P	Wood	X		90	90	100F					
33-3P	Wood			90	90	90	90	100F			
33-1C	Absorptive			50	50	50	70	80	80	80	90
33-3C	Absorptive			80	80	80	80	80	80	80	80
63-1C	Absorptive	Admixture	4.0	80	80	100F					
63-3C	Absorptive	X		60	60	60	100F				

Long-Time Study, Portland Cement Association

1941 Installation

In October 1941, 66 concrete beams (6- by 6- by 30-in.) were installed on the Treat Island exposure rack as a part of the program sponsored by the Advisory Committee on the Long-Time Study of Cement Performance in Concrete.

The aggregates used were a natural sand and gravel. The variables under study were:

a. Cements. Five nonair-entraining cements, two air-entraining cements containing 0.04 percent of air-entraining addition.

b. Placing. Hand placing versus vibration.

c. Form lining. Absorptive form lining versus wood lining (absorptive lining on one face only).

d. Cement factors. 5.0 and 7.0 bags per cu yd.

e. Slump. 2 and 8 in.

Table 1-PCA lists these specimens and gives their exposure record along with pertinent mixture information.

In 1943, the exposure of 18 beams in this series was discontinued; 17 of these beams were not reinstalled. The exposure of the remaining 48 beams was concluded in 1959: 46 of the beams had failed, one had been broken during handling and one had been lost overboard.

1954 Installation

In May 1954, 58 concrete beams (6- by 6- by 30-in.) were installed on the Treat Island exposure rack; all of these beams were made in 1941. Fifty-seven of these specimens had been stored indoors since 1941; the remaining beam (51-2A) had been previously exposed in the 1941 installation but had been stored indoors since August 1943. The aggregates and other mixture data used in the first installation apply to the beams in this installation.

Table 2-PCA lists these specimens and gives their exposure record along with other pertinent mixture information.

In 1967, with only two beams remaining, the exposure was discontinued; all of the other 56 specimens had failed. The two remaining beams were shipped back to the laboratory for petrographic examination; the petrographic report is shown as Appendix A.

Findings

Findings are summarized below:

a. Generally, concrete made with the air-entraining cements had greater durability than concrete made with the nonair-entraining cements.

b. The 7-bag-per-cu-yd concrete mixtures had greater durability than did the 5-bag-per-cu-yd concrete mixtures.

c. The vibrated concrete beams had generally better durability than did the hand-placed concrete beams. Since the 8-in.-slump concrete was always hand placed, it follows from the above that the 2-in.-slump concrete had generally better durability than the 8-in.-slump concrete.

d. The effect of form lining (wood versus absorptive) is not apparent from these test data.

e. For the vibrated 5-bag-per-cu-yd concrete mixture placed against wood lining the order of durability for the cements tested was as follows (most durable to least durable): cements 16T, 21T, 41, 11. Cement 12T was not tested in this mixture.

f. For the vibrated 5-bag-per-cu-yd concrete mixture placed against absorptive form lining (one face only) the most durable cements were 12T, 42, and 25. Cements 15 and 18 were the least durable. Cements 16T and 21T were not tested in this mixture.

g. For the vibrated 7-bag-per-cu-yd concrete mixture placed against wood lining the order of durability for the cements tested was as follows (most durable to least durable):

cements 21T, 42, 41 and 16T, 11. Cement 12T was not tested in this mixture.

h. For the vibrated 7-bag-per-cu-yd concrete mixture placed against absorptive form lining (one face only) the most durable cements were 12T, 25, 23, 14, and 33. Cements 43A and 22 were the least durable. Cements 16T and 21T were not tested in this mixture.

i. For the hand-placed 7-bag-per-cu-yd concrete mixture placed against wood lining the order of durability for the cements tested was as follows (most durable to least durable): Cements 21T, 16T, 11, 31. Cement 12T was not tested in this mixture.

j. For the hand-placed 7-bag-per-cu-yd concrete mixture placed against absorptive form lining (one face only) the most durable cements were 12T, 16, 33, and 25. Cements 18, 21, 42, and 43 were the least durable. Cements 16T and 21T were not tested in this mixture.

(Issued Sept 1968)

Table 1-PCA

Program 17

Mixture Data and Record of Testing of Concrete Beams, Long-Time Study, PCA

1941-1959 (Installed October 1941)

Beam No.	Type Cement*	Theo Cement Factor bags/cu yd	Method of Placing	Slump in.	Form Lining	1941-1948 Readings							
						0 Cycles 1941 %E	155 Cycles 1942 %E	351 Cycles 1943 %E	494 Cycles 1944 %E	604 Cycles 1945 %E	709 Cycles 1946 %E	821 Cycles 1947 %E	958 Cycles 1948 %E
11-1	I, (11)	5.0	Vibrated	2	Wood	100	86	F†					
11-2		7.0	Vibrated	2		100	103	102	F				
11-3		7.0	Hand	8		100	F						
12-1	I, (12)	5.0	Vibrated	2	Absorp-	100	93	F					
12-2		7.0	Vibrated	2	tive**	100	97	103	F				
12-3		7.0	Hand	8		100	86	92	92	83	F		
12T-1	I, air-entraining	5.0	Vibrated	2	Absorp-	100	98	100	103	93	F		
12T-2	(12T)	7.0	Vibrated	2	tive	100	103	110	112	108	112	112	107
12T-3		7.0	Hand	8		100	102	111	116	114	116	116	106
13-1	I, (13)	5.0	Vibrated	2	Absorp-	100	86	F					
13-2		7.0	Vibrated	2	tive	100	102	97	F				
13-3		7.0	Hand	8		100	100	103	F				
14-1	I, (14)	5.0	Vibrated	2	Absorp-	100	98	F					
14-2		7.0	Vibrated	2	tive	100	89	83	Removed from rack and stored, Aug 1943				
14-3		7.0	Hand	8		100	103	F					
15-1	I, (15)	5.0	Vibrated	2	Absorp-	100	F						
15-2		7.0	Vibrated	2	tive	100	100	97	Removed from rack and stored, Aug 1943				
15-3		7.0	Hand	8		100	91	F					
16-1	I, (16)	5.0	Vibrated	2	Absorp-	100	95	F					
16-2		7.0	Vibrated	2	tive	100	100	92	Removed from rack and stored, Aug 1943				
16-3		7.0	Hand	8		100	102	102	108	108	86	86	F
16T-1	I, air-entraining	5.0	Vibrated	2	Wood	100	97	105	108	108	105	105	84
16T-2	(16T)	7.0	Vibrated	2		100	105	97	100	64	F		
16T-3		7.0	Hand	8		100	103	106	108	113	111	111	104
18-1	I, (18)	5.0	Vibrated	2	Absorp-	100	F						
18-2		7.0	Vibrated	2	tive	100	93	103	F				
18-3		7.0	Hand	8		100	95	F					
21-1A	II, (21)	5.0	Vibrated	2	Absorp-	100	85	F					
21-2		7.0	Vibrated	2	tive	100	87	F					
21-3A		7.0	Hand	8		100	90	F					
21T-1	II, air-entraining	5.0	Vibrated	2	Wood	100	81	89	94	82	68	68	50F
21T-2	(21T)	7.0	Vibrated	2		100	75	107	110	109	107	107	102
21T-3		7.0	Hand	8		100	83	110	112	113	112	112	105
22-1	II, (22)	5.0	Vibrated	2	Absorp-	100	91	44F					
22-2		7.0	Vibrated	2	tive	100	83	70	Removed from rack and stored, Aug 1943				
22-3		7.0	Hand	8		100	97	79	Removed from rack and stored, Aug 1943				
23-1	II, (23)	5.0	Vibrated	2	Absorp-	100	94	55	Removed from rack and stored, Aug 1943				
23-2		7.0	Vibrated	2	tive	100	84	100	90	71	F		
23-3		7.0	Hand	8		100	95	60	Removed from rack and stored, Aug 1943				
24-1	II, (24)	5.0	Vibrated	2	Absorp-	100	95	F					
24-2		7.0	Vibrated	2	tive	100	88	F					
24-3		7.0	Hand	8		100	87	81	Removed from rack and stored, Aug 1943				
25-1	II, (25)	5.0	Vibrated	2	Absorp-	100	96	105	87	51	F		
25-2		7.0	Vibrated	2	tive	100	87	Lost overboard					
25-3		7.0	Hand	8		100	100	94	F				
31-1	III, (31)	5.0	Vibrated	2	Absorp	100	96	74	Removed from rack and stored, Aug 1943				
31-2		7.0	Vibrated	2	Absorp	100	84	89	Removed from rack and stored, Aug 1943				
31-3		7.0	Hand	8	Wood	100	F						
33-1	III, (33)	5.0	Vibrated	2	Absorp-	100	92	F					
33-2		7.0	Vibrated	2	tive	100	98	98	95	F			
33-3		7.0	Hand	8		100	100	104	104	F			
41-1	IV, (41)	5.0	Vibrated	2	Wood	100	81	64	Removed from rack and stored, Aug 1943				
41-2		7.0	Vibrated	2	Wood	100	89	62	F				
41-3		7.0	Hand	8	Absorp	100	98	F					
42-1	IV, (42)	5.0	Vibrated	2	Absorp	100	72	F					
42-2		7.0	Vibrated	2	Wood	100	81	72	74	94	104	104	70
42-3		7.0	Hand	8	Absorp	100	86	F					

(Continued)

* Program cement number given in parentheses.
** Absorptive form lining one face only.
† F denotes specimen has failed.

Program 17

Table 1-PCA (Concluded)

Beam No.	Type Cement	Theo Cement Factor bags/cu yd	Method of Placing	Slump in.	Form Lining	1941-1948 Readings: 0 Cycles 1941 %E	155 Cycles 1942 %E	351 Cycles 1943 %E	494 Cycles 1944 %E	604 Cycles 1945 %E	709 Cycles 1946 %E	821 Cycles 1947 %E	958 Cycles 1948 %E
43-1	IV, (43)	5.0	Vibrated	2	Absorp-	100	95	63	Removed from rack and stored, Aug 1943				
43-2		7.0	Vibrated	2	tive	100	63	F					
43-3		7.0	Hand	8		100	81	F					
43A-1	IV, (43A)	5.0	Vibrated	2	Absorp-	100	81	72	Removed from rack and stored, Aug 1943				
43A-2		7.0	Vibrated	2	tive	100	79	64	Removed from rack and stored, Aug 1943				
43A-3		7.0	Hand	8		100	89	93	Removed from rack and stored, Aug 1943				
51-1	V, (51)	5.0	Vibrated	2	Absorp-	100	102	69	Removed from rack and stored, Aug 1943				
51-2A		7.0	Vibrated	2	tive	100	95	65	Removed from rack and stored, Aug 1943				
51-3		7.0	Hand	8		100	100	94	Removed from rack and stored, Aug 1943				

Beam No.	Type Cement	Theo Cement Factor bags/cu yd	Method of Placing	Slump in.	Form Lining	1949-1954 Readings: 1063 Cycles 1949 %E	1224 Cycles 1950 %E	1313 Cycles 1951 %E	1414 Cycles 1952 %E	1499 Cycles, 1953 %E	1499 Cycles, 1953 Pulse Veloc fps	1499 Cycles, 1953 %V^2	1610 Cycles 1954 %E	1610 Cycles 1954 %V^2
12T-2	I, air-entraining	7.0	Vibrated	2	Absorp-	104	99	99	92	90	16,130	100	88	95
12T-3	(12T)	7.0	Hand	8	tive	103	96	96	99	100	16,130	100	93	96
16T-1	I, air-entraining	5.0	Vibrated	2	Wood	83	75	77	76	101	15,150	100	90	98
16T-3	(16T)	7.0	Hand	8		96	84	84	80	82	15,150	100	81	105
21T-2	II, air-entraining	7.0	Vibrated	2	Wood	102	88	90	82	82	13,440	100	50F	
21T-3	(21T)	7.0	Hand	8		105	96	95	95	93	14,970	100	93	100
42-2	IV	7.0	Vibrated	2	Wood	F								

Beam No.	Type Cement	Theo Cement Factor bags/cu yd	Method of Placing	Slump in.	Form Lining	1955-1959 Readings: 1755 Cycles 1955 %E	1755 Cycles 1955 %V^2	1922 Cycles 1956 %E	1922 Cycles 1956 %V^2	2066 Cycles 1957 %E	2066 Cycles 1957 %V^2	2137 Cycles 1958 %E	2137 Cycles 1958 %V^2	2287 Cycles 1959 %E	2287 Cycles 1959 %V^2
12T-2	I, air-entraining	7.0	Vibrated	2	Absorp-	50F									
12T-3	(12T)	7.0	Hand	8	tive	94	90	Broken in handling 1956							
16T-1	I, air-entraining	5.0	Vibrated	2	Wood	96	96	92	95	75	90	75	85	F	
16T-3	(16T)	7.0	Hand	8		83	99	82	100	77	89	77	95	F	
21T-3	II, air-entraining (21T)	7.0	Hand	8	Wood	96	95	89	93	74	88	F			

(Issued Sept 1968)

Table 2-PCA

Program 17

Mixture Data and Record of Testing of Concrete Beams, Long-Time Study, PCA

1954-1967 (Installed May 1954)

Beam No.	Type Cement*	Theo Cement Factor bags/cu yd	Method of Placing	Slump in.	Form Lining	0 Cycles, 1954 %E	0 Cycles, 1954 Pulse Veloc fps	0 Cycles, 1954 $\%V^2$	145 Cycles 1955 %E	145 Cycles 1955 $\%V^2$	312 Cycles 1956 %E	312 Cycles 1956 $\%V^2$	456 Cycles 1957 %E	456 Cycles 1957 $\%V^2$	527 Cycles 1958 %E	527 Cycles 1958 $\%V^2$	677 Cycles 1959 %E	677 Cycles 1959 $\%V^2$
11-1A	I, (11)	5.0	Vibrated	2	Wood	100	16,130	100	80	88	88	103	F†					
11-2A		7.0	Vibrated	2		100	16,445	100	98	104	100	103	104	92	92	99	95	82
11-3A		7.0	Hand	8		100	15,625	100	69	75	F							
12-1A	I, (12)	5.0	Vibrated	2	Absorp-	100	15,825	100	F									
12-2A		7.0	Vibrated	2	tive**	100	16,235	100	101	107	114	99	84	81	80	84	F	
12-3A		7.0	Hand	8		100	16,235	100	99	104	90	79	F					
12T-1A	I, air-	5.0	Vibrated	2	Absorp-	100	15,725	100	111	105	91	89	79	77	65	78	F	
12T-2A	entraining	7.0	Vibrated	2	tive	100	16,235	100	100	107	110	95	90	78	74	75	56	42
12T-3A	(12)	7.0	Hand	8		100	16,025	100	101	107	108	99	81	84	78	80	66	66
13-1A	I, (13)	5.0	Vibrated	2	Absorp-	100	16,130	100	48F									
13-2A		7.0	Vibrated	2	tive	100	16,340	100	101	107	101	91	90	68	74	--	F	
13-3A		7.0	Hand	8		100	15,625	100	40F									
14-1A	I, (14)	5.0	Vibrated	2	Absorp-	100	15,825	100	87	87	87	--	F					
14-2A		7.0	Vibrated	2	tive	100	16,130	100	121	110	122	100	121	87	103	80	99	--
14-3A		7.0	Hand	8		100	15,625	100	58	69	F							
15-1A	I, (15)	5.0	Vibrated	2	Absorp-	100	14,970	100	F									
15-2A		7.0	Vibrated	2	tive	100	16,890	100	101	103	105	94	84	74	70	71	F	
15-3A		7.0	Hand	8		100	15,925	100	85	93	85	--	F					
16-1A	I, (16)	5.0	Vibrated	2	Absorp-	100	15,825	100	123	46	F							
16-2A		7.0	Vibrated	2	tive	100	16,025	100	63	53	F							
16-3A		7.0	Hand	8		100	15,925	100	113	104	78	72	36F					
16T-1A	I, air-	5.0	Vibrated	2	Wood	100	15,725	100	101	107	93	96	82	79	70	82	63	68
16T-2A	entraining	7.0	Vibrated	2		100	15,925	100	99	110	101	110	101	99	88	107	86	93
16T-3A	(16T)	7.0	Hand	8		100	15,150	100	102	110	102	109	96	92	76	100	61	72
18-2A	I, (18)	7.0	Vibrated	2	Absorp-	100	16,235	100	101	108	92	95	93	69	97	--	F	
18-3A		7.0	Hand	8	tive	100	15,825	100	53	61	F							
21-1	II, (21)	5.0	Vibrated	2	Absorp-	100	15,335	100	F									
21-2A		7.0	Vibrated	2	tive	100	16,340	100	101	104	114	95	69	57	54	38	F	
21T-1A	III, air-	5.0	Vibrated	2	Wood	100	15,725	100	105	108	109	105	109	101	97	108	101	99
21T-2A	entraining	7.0	Vibrated	2		100	15,825	100	103	108	89	101	93	87	76	100	71	83
21T-3A	(21)	7.0	Hand	8		100	15,150	100	102	122	76	104	85	87	68	100	57	79
22-1A	II, (22)	5.0	Vibrated	2	Absorp-	100	14,535	100	F									
22-2A		7.0	Vibrated	2	tive	100	16,555	100	100	106	50F							
22-3A		7.0	Hand	8		100	16,025	100	102	104	102	61	F					
23-1A	II, (23)	5.0	Vibrated	2	Absorp-	100	15,925	100	94	65	F							
23-2A		7.0	Vibrated	2	tive	100	16,780	100	100	106	115	99	83	68	79	82	56	--
23-3A		7.0	Hand	8		100	16,555	100	85	91	41F							
24-1A	II, (24)	5.0	Vibrated	2	Absorp-	100	15,825	100	108	45	F							
24-2A		7.0	Vibrated	2	tive	100	16,340	100	102	103	110	103	74	49	71	--	69	--
24-3A		7.0	Hand	8		100	15,825	100	97	104	81	81	38F					
25-1A	II, (25)	5.0	Vibrated	2	Absorp-	100	16,025	100	100	98	81	77	45F					
25-2A		7.0	Vibrated	2	tive	100	16,665	100	101	103	118	103	68	72	78	96	62	71
25-3A		7.0	Hand	8		100	16,130	100	100	104	106	100	75	--	73	81	F	
31-1A	III, (31)	5.0	Vibrated	2	Absorp-	100	15,925	100	60	77	F							
31-2A		7.0	Vibrated	2	tive	100	16,235	100	99	97	86	70	46F					
33-1A	III, (33)	5.0	Vibrated	2	Absorp-tive	100	15,335	100	58	--	F							
41-1A	IV, (41)	5.0	Vibrated	2	Wood	100	16,235	100	102	105	102	103	81	102	96	96	71	64
41-2A		7.0	Vibrated	2	Wood	100	16,665	100	102	104	105	101	92	--	93	100	94	91
41-3A		7.0	Hand	8	Absorp-tive	100	16,130	100	102	99	105	85	37F					
42-1A	IV, (42)	5.0	Vibrated	2	Absorp-tive	100	16,025	100	100	110	101	110	77	--	72	--	56	56
42-2A		7.0	Vibrated	2	Wood	100	16,025	100	104	111	109	110	90	102	92	109	81	87
43-1A	IV, (43)	5.0	Vibrated	2	Absorp-	100	15,825	100	80	97	59	73	F					
43-2A		7.0	Vibrated	2	tive	100	16,235	100	104	103	104	101	80	83	77	84	56	54

(Continued)

-- End of specimen too rough to obtain satisfactory reading.
* Program cement number given in parentheses.
† F denotes specimen has failed.
** Absorptive form lining one face only.

Program 17

(Issued Sept 1968)

Table 2-PCA (Concluded)

Beam No.	Type Cement	Theo Cement Factor bags/cu yd	Method of Placing	Slump in.	Form Lining	0 Cycles, 1954 %E	0 Cycles, 1954 Pulse Veloc fps	0 Cycles, 1954 $\%V^2$	145 Cycles 1955 %E	145 Cycles 1955 $\%V^2$	312 Cycles 1956 %E	312 Cycles 1956 $\%V^2$	456 Cycles 1957 %E	456 Cycles 1957 $\%V^2$	527 Cycles 1958 %E	527 Cycles 1958 $\%V^2$	677 Cycles 1959 %E	677 Cycles 1959 $\%V^2$
						1954-1959 Readings												
43A-1A	IV, (43A)	5.0	Vibrated	2	Absorp-	100	16,130	100	60	85	35F							
43A-2A		7.0	Vibrated	2	tive	100	16,340	100	80	91	57	76	F					
51-1A	V, (51)	5.0	Vibrated	2	Absorp-	100	15,925	100	68	83	F							
51-2A		7.0	Vibrated	2	tive	100	14,620	100	90	101	F							
51-3A		7.0	Hand	8		100	15,925	100	89	86	89	--	F					

Beam No.	Type Cement	Theo Cement Factor bags/cu yd	Method of Placing	Slump in.	Form Lining	748 Cycles 1960 %E	748 Cycles 1960 $\%V^2$	889 Cycles 1961 %E	889 Cycles 1961 $\%V^2$	978 Cycles 1962 %E	978 Cycles 1962 $\%V^2$	1084 Cycles 1963 %E	1084 Cycles 1963 $\%V^2$	1219 Cycles 1964 %E	1219 Cycles 1964 $\%V^2$	1382 Cycles 1965 %E	1382 Cycles 1965 $\%V^2$	1512 Cycles 1966 %E	1512 Cycles 1966 $\%V^2$
						1960-1966 Readings													
11-2A	I, (11)	7.0	Vibrated	2	Wood	87	--	F											
12T-2A	I, air-	7.0	Vibrated	2	Absorp-	F													
12T-3A	entraining (12T)	7.0	Hand	8	tive	61	64	F											
14-2A	I, (14)	7.0	Vibrated	2	Absorp- tive	70	--	F											
16T-1A	I, air-	5.0	Vibrated	2	Wood	62	--	100	--	89	--	F							
16T-2A	entraining	7.0	Vibrated	2		78	94	69	89	60	83	54	--	54	--	F	--		
16T-3A	(16T)	7.0	Hand	8		50F													
21T-1A	II, air-	5.0	Vibrated	2	Wood	100	103	96	103	92	105	92	111	90	99	88	88	85	92
21T-2A	entraining	7.0	Vibrated	2		65	86	68	65	62	76	73	--	F					
21T-3A	(21T)	7.0	Hand	8		51	77	53	65	39F	52								
23-2A	II, (23)	7.0	Vibrated	2	Absorp- tive	74	--	F											
24-2A	II, (24)	7.0	Vibrated	2	Absorp- tive	F													
25-2A	II, (25)	7.0	Vibrated	2	Absorp- tive	69	--	69	--	55	--	F							
41-1A	IV, (41)	5.0	Vibrated	2	Wood	100	--	100	--	NR††	--	NR	--	F					
41-2A		7.0	Vibrated	2		67	97	88	94	82	95	79	94	63	79	51	73	58	--
42-1A	IV, (42)	5.0	Vibrated	2	Absorp- tive	46F													
42-2A		7.0	Vibrated	2	Wood	82	92	76	--	60	--	F							
43-2A	IV, (43)	7.0	Vibrated	2	Absorp- tive	50F													

Beam No.	Type Cement	Theo Cement Factor bags/cu yd	Method of Placing	Slump in.	Form Lining	1668 Cycles 1967 (Final) %E	1668 Cycles 1967 (Final) $\%V^2$
						1967 Readings	
21T-1A	II, air-entraining (21T)	5.0	Vibrated	2	Wood	83	92
41-2A	IV, (41)	7.0	Vibrated	2	Wood	35	--

-- End of specimen too rough to give satisfactory reading.

†† NR denotes a satisfactory reading was not obtained as specimen would not respond to flexural vibration.

Appendix A: Petrographic Report

Samples

1. In 1967 two 6- by 6- by 30-in. concrete beams were returned to the laboratory from the exposure station at Treat Island, Maine. They were two of 58 beams made at the Portland Cement Association in 1941 and placed on the outdoor exposure racks in 1954. These were the only two beams remaining in 1967 after 1668 cycles of freezing and thawing, and one of them had failed between the 1966 and 1967 readings. Some data on the two beams are shown below:

Beam No.	Cement Type	Cement Factor bags/cu yd	Slump in.	Remarks
21T-1A	II	5	2	Air-entrained concrete
41-2A	IV	7	2	Nonair-entrained concrete

Both beams contain natural sand and gravel from Plainfield, Illinois. The maximum size of aggregate appeared to be 3/4 in.

2. Some of the field test data are shown below:

Year	1954	1960	1961	1963	1964	1967
No. of freezing-and-thawing cycles	0	748	889	1084	1219	1668
Beam:	Relative E, %					
21T-1A	100	100	96	92	90	83
41-2A	100	67	88	79	63	35 (failed)

3. The examination was made to determine why the durability of these two beams was appreciably better than that of the other 56 beams.

Test Procedure

4. Data on the air-void system of each concrete were obtained

by the micrometric method, CRD-C 42.*

5. Sawed surfaces and freshly broken surfaces of each beam were examined with a stereomicroscope.

Results

6. Data on the air-void system of the two specimens are shown below:

	Beam 21T-1A	Beam 41-2A
Entrained air, %	3.62	1.25
Entrapped air, %	1.28	1.53
Total air, %	4.90	2.78
n, No. of voids per in.	5.5	1.3
$\bar{L}$, void spacing factor, in.	0.01	0.03

7. Beam 41-2A failed between the 1966-1967 field readings, and one end fell off. Beam 21T-1A did not fail, and it was still intact when examined. However, there were numerous internal cracks in both beams. Some of these cracks passed through aggregate particles.

8. Most of the coarse-aggregate particles were carbonate rock. The fine aggregate was largely a mixture of quartz grains, chert, and carbonate-rock fragments.

9. Some voids in the two concretes contained some calcium sulfoaluminate deposits and some old cracks were partially coated with it. There may have been a few patches of alkali-silica gel, and some of the carbonate particles showed reaction rims. However, no deleterious chemical reactions were anticipated, and the extent of reaction recognized is not regarded as a factor affecting the performance of the concretes.

10. The reasons for the fluctuating E values for beam 41-2A between 1959-1963 is unknown, but it is assumed to be due to operators or equipment or differences in moisture content of the specimen rather than to real changes in the condition of concrete.

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* U. S. Army Engineer Waterways Experiment Station, CE, Handbook for Concrete and Cement, Aug 1949 (with quarterly supplements), Vicksburg, Miss. (identical to ASTM Designation: C 547-66T).

Discussion

11. It was not possible to determine why these two beams were so durable in the field exposure by direct comparison with the other less durable 56, since none of them were available for examination.

12. In spite of the lack of comparative data, examination of the micrometric air data and of the field data for all 58 beams leads to some conclusions that tend to verify known or anticipated results.

13. The internal cracking of beam 21T-1A is the effect of frost action; its decreasing E value in recent years is also due to frost action. One may conclude that a void-spacing factor of 0.01 in. is adequate to greatly improve the durability of concrete. Note, however, that the protection was only effective for about 15 years. Other workers have shown that, if concrete does not have an opportunity for drying, it needs a void spacing factor of 0.008 in. or less to be durable. All of these data serve to emphasize the importance of degree of saturation in the frost durability of concrete.

14. The other conclusion may be reached by examination of the field data for durability. These indicate that, if concrete is not protected by air-entrainment, then low permeability is probably the key to improved durability. In general, the best durability among the nonair-entrained concretes was enjoyed by those combining the highest cement factors with low slump, presumably related to low water-cement ratio and low permeability.

Summary

15. Two concrete beams, representing air-entrained and a nonair-entrained concrete, were examined after 13 years of exposure at Treat Island, Maine. The good durability of beam 21T-1A is due to its air-void system, which provided protection under these exposure conditions for about 15 years. It therefore follows that air-entrained concrete may be protected for a period of time with a void-spacing factor of 0.01 in. or larger if it has adequate drying between freezing cycles.

16. It was also concluded that, in the absence of the protection afforded by air entrainment, low permeability is the next best protection and that low permeability was probably responsible for the good durability of beam 41-2A.

Vacuum Treatment Investigation*

The purpose of this installation was to determine the influence of a vacuum treatment on the durability of concrete. Vacuum treatment is a process whereby some of the "extra" water required in the concrete for workability, and which is in excess of that required for the hydration of the cement, is extracted from the concrete after it is placed and consolidated, but while it is in the plastic state. The process, as the name implies, utilizes the principle of application of vacuum through suitable chambers that are in contact with the concrete surface.

In October 1949, 46 concrete cores were installed on the Treat Island exposure rack as a part of this study of vacuum-treated air-entrained concrete. Thirty-six of these cores were 10 in. in diameter, either 16 or 18 in. long, and contained 6-in. maximum size aggregate. The remaining ten cores were 8 in. in diameter, 9-1/2 in. long, and contained 3-in. maximum size aggregate. All cores were diamond-drilled either from a 133-cu-yd test block or from one of seven horizontal slabs. The surfaces of the large test block and of six of the seven slabs were vacuum treated, which affected 28 cores. The aggregates used consisted of crushed limestone and manufactured limestone sand.

Tables 1-VP and 2-VP list the 10-in.- and 8-in.-diameter cores, respectively, and give their exposure records along with other pertinent information.

The exposure of these cores was terminated in 1966 after 2059 cycles of freezing-and-thawing (17 winters). Twenty-seven of the cores survived the exposure (six 8-in. diameter cores and 21 large cores).

Findings

Small cores (8-in. diameter)

The ten small cores (8 in. in diameter) were all made from the same concrete mixture; the only variable was the treatment after placement of the concrete. Two of the cores (HA-5 and HA-6) were drilled from concrete

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* See U. S. Army Engineer Waterways Experiment Station, CE, Investigation of Vacuum Treatment of Mass Concrete Surfaces, Technical Memorandum No. 6-353 (Vicksburg, Miss., February 1953).

that was not vacuum treated; the other eight cores were from concrete that was vacuum treated as follows:

Core No.	Time of Vacuum Treatment
HB-5, HB-6	Immediately after screeding
HC-5, HC-6	Approx 3-1/2 hr after mixing
HD-5, HD-6	Approx 2 hr after mixing
HH-5, HH-6	Approx 2 hr after mixing

The cores that were not vacuum treated (HA-5 and HA-6) and the cores that were vacuum treated immediately after screeding (HB-5 and HB-6) did not survive the Treat Island exposure. The six cores that were vacuum treated either 2 or 3-1/2 hr after mixing survived the full exposure and had essentially equal resistance to the natural weathering. From this exposure it is concluded that: The vacuum treatment applied either 2 or 3-1/2 hr after mixing improved the durability of the small concrete cores to the Treat Island exposure.

Large cores (10-in. diameter)

Each of the 10-in.-diameter cores was drilled from concrete of one of the following four mixtures:

Mixture	No. of Cores Exposed	Vacuum Treated	Max Size Aggregate in.	Air, %	Cement Factor bags/cu yd	Water-Cement Ratio gal/bag
A	16	No	6	3.2	3.0	7.0
B	6	Yes	6	2.8	4.0	6.0
C	10	Yes	6	3.2	3.0	7.0
D	4	Yes	6	2.8	4.0	5.4

The order of durability for the four mixtures was as follows (most durable to least durable): mixture D; mixture C; mixture A; and mixture B.

Since mixture A and mixture C were identical except for the vacuum treatment and mixture C had better durability than mixture A it is concluded that the vacuum treatment improved the durability of the large concrete cores to the Treat Island exposure.

Thirty* of the 10-in.-diameter cores were drilled from the 133-cu-yd test block which was cast in three lifts. Fifteen cores were drilled from lift 1, eleven from lift 2, and four from lift 3. The order of durability by lift was as follows (most durable to least durable): Lift 2, lift 3, lift 1. It is believed that this order of durability can probably be explained by the fact that the cores from lift 2 contained no mixture B concrete (mixture B was the least durable mixture) and that quite a few of the cores from lift 1 were made of mixture B concrete.

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* Location of these cores by lift is as follows:

Lift 1 (15 cores)	Lift 2 (11 cores)	Lift 3 (4 cores)
VS-3I, -30	VB-12I, -120	VB-21I, -210
VS-6I, -60	VF-120	VF-21I, -210
VB-3I, -30	VB-15I, -150	
VB-6I, -60	VB-18I, -180	
VB-9I, -90	VF-15I, -150	
VF-30	VF-18I, -180	
VF-6I, -60		
VF-9I, -90		

(Issued Sept 1968)

Table 1-VP

Program 18

Mixture Data and Record of Testing of Large (10-in. Diameter) Concrete Cores, Vacuum Treatment Investigation

1949-1966 (Installed October 1949)

Maximum-size Aggregate 6 in.

Core No.	Vacuum-treated	Air %	Cement Factor bags/cu yd	Water-cement Ratio gal/bag	1949-1956 Readings: 0 Cycles 1949 %E	89 Cycles 1950 %E	250 Cycles 1951 %E	351 Cycles 1952 %E	436 Cycles, 1953			547 Cycles 1954		692 Cycles 1955		859 Cycles 1956	
									%E	Pulse Veloc fps	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$
VS-3I	No	3.2	3.0	7.0	100	101	101	108	108	17,440	100	102	93	99	100	99	89
VS-30	Yes	3.2	3.0	7.0	100	102	108	107	107	17,175	100	111	106	102	106	96	90
VS-6I	No	3.2	3.0	7.0	100	104	109	108	102	15,285	100	104	88	100	110	112	103
VS-60	Yes	3.2	3.0	7.0	100	105	113	103	102	14,945	100	101	116	109	115	110	113
VB-3I	No	3.2	3.0	7.0	100	107	113	113	114	16,625	100	116	96	122	100	122	98
VB-30	Yes	2.8	4.0	6.0	100	113	112	113	111	15,465	100	111	103	106	122	103	113
VB-6I	No	3.2	3.0	7.0	100	106	110	107	114	15,645	100	115	116	115	116	120	93
VB-60	Yes	2.8	4.0	6.0	100	107	112	114	115	15,835	100	112	117	117	120	134	90
VB-9I	No	3.2	3.0	7.0	100	107	110	113	118	16,855	100	114	105	114	102	119	92
VB-90	Yes	2.8	4.0	6.0	100	103	102	97	89	16,665	100	84	100	77	90	82	98
VB-12I	No	3.2	3.0	7.0	100	105	109	110	111	15,835	100	116	108	112	105	119	94
VB-120	Yes	2.8	4.0	5.4	100	107	*	116	110	16,625	100	108	106	108	100	114	93
VB-15I	No	3.2	3.0	7.0	100	110	107	110	113	16,130	100	117	104	115	109	115	100
VB-150	Yes	2.8	4.0	5.4	100	108	114	115	113	17,645	100	118	89	117	89	122	89
VB-18I	No	3.2	3.0	7.0	100	115	118	116	116	15,465	100	113	103	116	91	115	96
VB-180	Yes	3.2	3.0	7.0	100	101	103	106	107	16,025	100	108	111	102	108	110	105
VB-21I	No	3.2	3.0	7.0	100	112	112	116	116	16,835	100	113	103	106	93	127	96
VB-210	Yes	3.2	3.0	7.0	100	108	110	113	114	16,420	100	112	114	113	106	110	106
VF-30	Yes	2.8	4.0	6.0	100	105	110	109	113	17,045	100	114	102	107	105	70	102
VF-6I	No	3.2	3.0	7.0	100	103	100	103	98	16,835	100	97	77	96	93	96	93
VF-60	Yes	2.8	4.0	6.0	100	107	110	112	111	16,835	100	110	109	116	103	116	---
VF-9I	No	3.2	3.0	7.0	100	71	72	F**									
VF-90	Yes	2.8	4.0	6.0	100	105	110	112	115	17,050	100	107	112	113	103	128	†
VF-120	Yes	2.8	4.0	5.4	100	162	162	149	163	15,465	100	170	106	160	106	151	102
VF-15I	No	3.2	3.0	7.0	100	106	107	112	115	15,955	100	116	98	117	102	118	96
VF-150	Yes	2.8	4.0	5.4	100	105	108	107	112	16,485	100	108	107	109	105	119	100
VF-18I	No	3.2	3.0	7.0	100	106	108	108	116	15,835	100	114	120	108	120	114	111
VF-180	Yes	3.2	3.0	7.0	100	105	107	107	110	16,220	100	99	117	99	108	106	94
VF-21I	No	3.2	3.0	7.0	100	101	95	94	90	15,835	100	98	126	92	120	92	116
VF-210	Yes	3.2	3.0	7.0	100	107	109	104	104	17,275	100	111	112	113	103	117	98
HE-5	Yes	3.2	3.0	7.0	100	111	111	116	122	15,790	100	119	109	118	102	121	96
HE-6	Yes	3.2	3.0	7.0	100	106	111	114	122	15,955	100	121	114	118	104	122	100
HF-5T	Yes	3.2	3.0	7.0	100	106	106	107	105	16,855	100	90	102	94	100	88	88
HF-5B	No	3.2	3.0	7.0	100	112	114	112	112	16,485	100	106	109	102	90	92	84
HF-6T	Yes	3.2	3.0	7.0	100	112	114	114	114	16,665	100	103	105	108	102	107	100
HF-6B	No	3.2	3.0	7.0	100	102	90	50F									

Core No.	Vacuum-treated	Air %	Cement Factor bags/cu yd	Water-cement Ratio gal/bag	1957-1964 Readings: 1003 Cycles 1957		1074 Cycles 1958		1224 Cycles 1959		1295 Cycles 1960		1436 Cycles 1961		1525 Cycles 1962		1631 Cycles 1963		1766 Cycles 1964	
					%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$
VS-3I	No	3.2	3.0	7.0	99	93	99	95	89	87	89	87	94	91	78	66	F	80		
VS-30	Yes	3.2	3.0	7.0	93	92	93	96	75	99	74	82	75	75	86	---	F	---		
VS-6I	No	3.2	3.0	7.0	112	113	93	108	93	103	96	101	102	105	85	96	69	110	67	89
VS-60	Yes	3.2	3.0	7.0	102	108	109	111	100	92	97	99	94	113	95	103	91	118	95	105
VB-3I	No	3.2	3.0	7.0	122	106	131	106	133	91	133	98	131	96	123	85	123	106	129	108
VB-30	Yes	2.8	4.0	6.0	100	122	85	111	103	103	104	106	83	98	71	96	63	116	62	82
VB-6I	No	3.2	3.0	7.0	115	103	117	107	116	86	117	95	111	105	105	108	101	103	103	85
VB-60	Yes	2.8	4.0	6.0	117	97	125	110	108	83	110	91	108	111	68	103	66	116	66	93
VB-9I	No	3.2	3.0	7.0	119	105	123	103	125	88	125	92	117	90	111	90	108	79	96	90
VB-90	Yes	2.8	4.0	6.0	82	96	F													
VB-12I	No	3.2	3.0	7.0	116	103	125	108	128	89	127	85	122	94	110	105	104	103	110	85
VB-120	Yes	2.8	4.0	5.4	108	105	100	100	105	94	101	94	100	91	89	93	89	100	91	80
VB-15I	No	3.2	3.4	7.0	113	107	115	102	114	85	112	88	114	88	106	90	106	53	105	92
VB-150	Yes	2.8	4.0	5.4	120	102	120	95	123	87	123	80	114	89	111	82	103	89	105	68
VB-18I	No	3.2	3.0	7.0	112	116	108	108	101	91	114	95	103	92	101	94	101	96	110	82

(Continued)

--- End of specimen too rough to obtain satisfactory reading.
* Satisfactory reading was not obtained as specimen would not respond to flexural vibration.
** F denotes specimen has failed.
† A spurious reading was obtained and was discarded.

Program 18

(Issued Sept 1968)

Table 1-VP (Concluded)

Core No.	Vacuum-treated	Air %	Cement Factor bags/cu yd	Water-cement Ratio gal/bag	1957-1964 Readings: 1003 Cycles 1957 %E	1003 Cycles 1957 $\%V^2$	1074 Cycles 1958 %E	1074 Cycles 1958 $\%V^2$	1224 Cycles 1959 %E	1224 Cycles 1959 $\%V^2$	1295 Cycles 1960 %E	1295 Cycles 1960 $\%V^2$	1436 Cycles 1961 %E	1436 Cycles 1961 $\%V^2$	1525 Cycles 1962 %E	1525 Cycles 1962 $\%V^2$	1631 Cycles 1963 %E	1631 Cycles 1963 $\%V^2$	1766 Cycles 1964 %E	1766 Cycles 1964 $\%V^2$
VB-180	Yes	3.2	3.0	7.0	100	105	106	105	106	91	100	91	98	91	88	96	78	100	60	105
VB-21I	No	3.2	3.0	7.0	111	105	123	102	117	88	118	86	97	89	95	91	97	98	95	82
VB-210	Yes	3.2	3.0	7.0	109	109	115	109	111	90	108	94	114	98	95	91	91	103	76	98
VF-30	Yes	2.8	4.0	6.0	70	.114	72	87	F											
VF-6I	No	3.2	3.0	7.0	77	95	85	97	74	80	68	76	75	85	48F	72				
VF-60	Yes	2.8	4.0	6.0	116	--	116	--	116	--	F									
VF-90	Yes	2.8	4.0	6.0	115	102	124	102	135	86	113	86	112	89	106	95	94	87	92	82
VF-120	Yes	2.8	4.0	5.4	153	113	159	106	166	98	157	106	156	96	148	98	144	130	147	98
VF-15I	No	3.2	3.0	7.0	116	98	123	100	118	87	118	89	116	96	111	94	109	98	112	--
VF-150	Yes	2.8	4.0	5.4	113	105	120	94	120	83	120	87	116	96	104	98	92	92	97	83
VF-18I	No	3.2	3.0	7.0	103	120	106	108	96	120	100	103	105	111	91	--	95	92	93	93
VF-180	Yes	3.2	3.0	7.0	106	101	106	112	95	94	103	92	105	98	96	93	78	98	77	89
VF-21I	No	3.2	3.0	7.0	84	122	92	116	81	--	80	--	51	--	F					
VF-210	Yes	3.2	3.0	7.0	114	112	114	103	86	89	85	91	83	93	F	98				
HE-5	Yes	3.2	3.0	7.0	115	109	122	100	123	92	115	96	116	96	103	90	109	96	98	98
HE-6	Yes	3.2	3.0	7.0	118	102	120	102	114	90	110	94	107	94	94	92	93	96	111	94
HF-5T	Yes	3.2	3.0	7.0	88	79	103	77	116	--	F									
HF-5B	No	3.2	3.0	7.0	92	71	92	78	92	--	F									
HF-6T	Yes	3.2	3.0	7.0	98	105	87	100	86	81	85	90	94	88	68	71	F	100		

Core No.	Vacuum-treated	Air %	Cement Factor bags/cu yd	Water-cement Ratio gal/bag	1965-1966 Readings: 1929 Cycles 1965 %E	1929 Cycles 1965 $\%V^2$	2059 Cycles 1966 (Final) %E	2059 Cycles 1966 (Final) $\%V^2$
VS-6I	No	3.2	3.0	7.0	60	88	60	73
VS-60	Yes	3.2	3.0	7.0	96	124	92	90
VB-3I	No	3.2	3.0	7.0	136	111	131	91
VB-30	Yes	2.8	4.0	6.0	F			
VB-6I	No	3.2	3.0	7.0	101	116	F	85
VB-60	Yes	2.8	4.0	6.0	64	116	66	80
VB-9I	No	3.2	3.0	7.0	102	98	96	100
VB-12I	No	3.2	3.0	7.0	106	89	119	93
VB-120	Yes	2.8	4.0	5.4	90	89	77	77
VB-15I	No	3.2	3.4	7.0	102	--	83	--
VB-150	Yes	2.8	4.0	5.4	123	85	90	98
VB-18I	No	3.2	3.0	7.0	119	92	119	93
VB-180	Yes	3.2	3.0	7.0	64	96	84	87
VB-21I	No	3.2	3.0	7.0	97	--	97	--
VB-210	Yes	3.2	3.0	7.0	70	91	69	81
VF-90	Yes	2.8	4.0	6.0	89	91	88	49
VF-120	Yes	2.8	4.0	5.4	144	104	140	62
VF-15I	No	3.2	3.0	7.0	112	--	104	--
VF-150	Yes	2.8	4.0	5.4	96	94	92	83
VF-18I	No	3.2	3.0	7.0	94	111	86	83
VF-180	Yes	3.2	3.0	7.0	85	106	79	81
HE-5	Yes	3.2	3.0	7.0	98	88	98	76
HE-6	Yes	3.2	3.0	7.0	113	92	110	65

-- End of specimen too rough to obtain satisfactory reading.

(Issued Sept 1968)

Table 2-VP

Mixture Data and Observations of Small (8-in. Diameter) Concrete Cores, Vacuum Treatment Investigation

1949-1966 (Installed October 1949)

Air content, 3.4%
Cement factor, 4.0 bags per cu yd
Maximum size aggregate, 3 in.
Water-cement ratio, 6.5 gal per bag

		1949-1958 Readings					
Core No.	Vacuum-treated	0 Cycles 1949 Condition	547 Cycles 1954 Condition	692 Cycles 1955 Condition	859 Cycles 1956 Condition	1003 Cycles 1957 Condition	1074 Cycles 1958 Condition
HA-5	No	Sound	Sound	Sound	Sound	Sound	Sound
HA-6		Sound	Sound	Sound	Sound	Sound	Sound
HB-5	Yes	Sound	Sound	Sl* scaling	Scaling, spalling	Hy** scaling, spalling	Hy scaling, spalling
HB-6		Sound	Sound	Sound	Sound	Sl spalling	Sl spalling
HC-5	Yes	Sound	Sound	Sound	Sound	Sound	Sound
HC-6		Sound	Sound	Sound	Sound	Sound	Sound
HD-5	Yes	Sound	Sound	Sound	Sound	Sl scaling	Sl scaling
HD-6		Sound	Sound	Sound	Sl spalling	Spalling	Sl scaling, spalling
HH-5	Yes	Sound	Sound	Sl spalling	Sl scaling, spalling	Sl scaling, spalling	Sl scaling, spalling
HH-6		Sound	Sound	Sl spalling	Sl spalling	Sl scaling, spalling	Sl scaling, spalling

		1959-1962 Readings			
Core No.	Vacuum-treated	1224 Cycles 1959 Condition	1295 Cycles 1960 Condition	1436 Cycles 1961 Condition	1525 Cycles 1962 Condition
HA-5	No	Sl spalling	Sl spalling	Moderate spalling	Moderate spalling
HA-6		Sl spalling	Sl spalling	Hy spalling, cracking	Middle gone, F†
HB-5	Yes	Hy scaling, spalling	Hy scaling, hy spalling	Hy scaling, hy spalling, cracking	End gone, F
HB-6		Spalling	Spalling	Moderate spalling	Moderate spalling
HC-5	Yes	Sound	Sound	Sound	Sound
HC-6		Hy spalling, cracking	Hy spalling, cracking	Hy spalling, cracking	Hy spalling, cracking
HD-5	Yes	Sl scaling	Sl scaling	Sl scaling, sl spalling	Sl scaling, mod spalling
HD-6		Sl scaling, hy spalling	Sl scaling, hy spalling	Sl scaling, hy spalling	Sl scaling, hy spalling
HH-5	Yes	Sl scaling, hy spalling	Sl scaling, hy spalling	Sl scaling, hy spalling	Sl scaling, hy spalling
HH-6		Sl scaling, hy spalling	Sl scaling, hy spalling	Sl scaling, hy spalling	Sl scaling, hy spalling

		1963-1966 Readings			
Core No.	Vacuum-treated	1631 Cycles 1963 Condition	1766 Cycles 1964 Condition	1929 Cycles 1965 Condition	2059 Cycles 1966 Condition (Final)
HA-5	No	Hy spalling	Hy spalling	Hy spalling, cracking, end gone, F	
HB-6	Yes	Moderate spalling	Moderate spalling	Hy spalling, end gone, F	
HC-5	Yes	Sl spalling	Hy spalling	Hy spalling	Hy spalling
HC-6		Hy spalling, cracking	Hy spalling, cracking	Hy spalling, cracking	Hy spalling, cracking
HD-5	Yes	Sl scaling, moderate spalling	Sl scaling, moderate spalling	Sl scaling, moderate spalling	Sl scaling, moderate spalling
HD-6		Sl scaling, hy spalling	Sl scaling, hy spalling	Sl scaling, hy spalling	Sl scaling, hy spalling
HH-5	Yes	Sl scaling, hy spalling	Sl scaling, hy spalling	Sl scaling, hy spalling	Sl scaling, hy spalling
HH-6		Sl scaling, hy spalling	Sl scaling, hy spalling	Sl scaling, hy spalling	Sl scaling, hy spalling

* Sl = slight.
** Hy = heavy.
† F = failed.

Preplaced Aggregate Cores*

The purpose of this installation was to develop data on the durability of preplaced aggregate concrete. Preplaced aggregate concrete is made by packing forms with coarse aggregate and then pumping in a cement-base intrusion mixture (grout) to fill the voids.

In October 1949, nine concrete cores (10 in. in diameter by 16 in. long) were installed on the Treat Island exposure rack as a part of this investigation. These cores were diamond drilled vertically through the 10-ft thickness of a 72-cu-yd test block of preplaced aggregate concrete. The test block was analogous to a portion of a dam and was grouted in three stages. The cores were taken as follows:

Core No.	Depth from Top of Block ft	Stage of Grouting	Core No.	Depth from Top of Block ft	Stage of Grouting
4A	+0.2-2.1	Third	8A	+0.1-1.8	Third
4B	2.1-4.2	Third	8B	1.8-3.7	Third
4D	6.0-8.2	Second	8C	3.7-5.8	Second-third
4E	8.2-9.9	First	8D	5.8-7.9	Second
			8E	7.9-10.0	First

The aggregates used consisted of granite coarse aggregate and manufactured limestone sand. The preplaced coarse aggregate was grouted with a mixture consisting of sand, type II portland cement (grout filler), an aid to intrusion, and water.

Table 1-PK lists these specimens and gives their exposure record together with other pertinent information.

The exposure of these cores was terminated in 1966 after 2059 cycles of freezing-and-thawing (17 winters). Only two of the cores survived the exposure; both of these were from the third grouting stage of hole No. 4 (core Nos. 4A and 4B).

* See U. S. Army Engineer Waterways Experiment Station, CE, Investigation of the Suitability of Prepakt Concrete for Mass and Reinforced Concrete Structures, Technical Memorandum No. 6-330 (Vicksburg, Miss., October 1951).

Findings

a. The cores taken from hole 4 (cores 4A, 4B, 4D, and 4E) had better durability than the corresponding cores from hole 8 (cores 8A, 8B, 8D, and 8E).

b. Cores taken from the third grouting stage (cores 4A, 4B, 8A, and 8B) had better durability than cores taken from the first and second grouting stages.

c. Cores taken from the first grouting stage (cores 4E and 8E) were slightly more durable than cores taken from the second grouting stage (cores 4D and 8D).

d. In general, this exposure demonstrated that good durable concrete can be obtained from preplaced aggregate concrete that has been properly placed. Cores 4A and 4B were still integral in 1966 after 17 winters of exposure to severe weathering at Treat Island.

(Issued Sept 1968)

Table 1-PK

Program 19

Record of Testing of Concrete Cores, Preplaced Aggregate Investigation

1949-1966 (Installed October 1949)

Air content, 3.2-4.6%
Water-cement and grout filler ratio, 0.60 (by wt)
Cement factor, 1.6-1.8 bags per cu yd
Maximum size aggregate, 3 in.

	1949-1959 Readings																				
Core No.	0 Cycles 1949	89 Cycles 1950	250 Cycles 1951	351 Cycles 1952	436 Cycles, 1953			547 Cycles 1954		692 Cycles 1955		859 Cycles 1956		1003 Cycles 1957		1074 Cycles 1958		1224 Cycles 1959			
	%E	%E	%E	%E	%E	Pulse Veloc fps	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$		
4A	100	110	113	117	124	15,645	100	120	113	123	116	130	98	128	84	134	108	139	103		
4B	100	106	113	121	113	15,285	100	116	113	118	105	131	96	123	110	128	111	133	102		
4D	100	113	113	112	120	15,115	100	123	110	123	102	132	96	113	113	124	112	131	88		
4E	100	112	115	116	128	15,645	100	124	113	125	103	135	96	131	108	131	108	131	93		
8A	100	111	114	118	116	15,285	100	118	116	121	108	130	103	125	119	130	109	126	94		
8B	100	111	112	117	120	15,465	100	119	111	124	100	129	**	126	**	131	**	130	**		
8C	100	113	106	119	112	14,780	100	117	113	117	98	F*									
8D	100	107	107	98	81	14,615	100	78	--	50 F											
8E	100	106	104	100	105	14,780	100	70	105	50 F											

	1960-1966 Readings													
Core No.	1295 Cycles 1960		1436 Cycles 1961		1525 Cycles 1962		1631 Cycles 1963		1766 Cycles 1964		1929 Cycles 1965		2059 Cycles 1966 (Final)	
	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$
4A	141	103	131	103	126	100	129	72	127	110	121	126	132	84
4B	143	100	133	100	128	110	124	94	132	100	123	105	137	93
4D	131	--	F											
4E	128	91	105	90	105	--	F	--						
8A	130	96	123	100	111	110	118	84	88	77	70	--	F	
8B	133	**	128	100	118	98	112	84	108	79	66	--	F	

-- End of specimen too rough to obtain satisfactory reading.
* F denotes specimen has failed.
** End gone from specimen, this precluded satisfactory reading using original path. In 1961 readings were resumed using another path.

Cooperative Study of Air-Entrained Concrete

In November 1951, 48 concrete beams (3- by 4- by 16-in.) were installed on the Treat Island exposure rack as a part of a cooperative program, conducted in conjunction with the National Sand and Gravel Association and the Bureau of Public Roads, to study the effects of entrained air on the durability of concrete. Half of the beams were made of nonair-entrained concrete, the other half of air-entrained concrete. Four water-cement ratios and two slumps were used. The 48 beams were made from 16 concrete mixtures (three beams per mixture) as shown below:

Mixture No.	Type Concrete	Water-Cement Ratio gal/bag	Slump in.	Air, %
1P	Nonair-entrained	4.5	2-1/2	
1A	Air-entrained	4.5	2-1/2	3.6
2P	Nonair-entrained	6.0	2-1/2	
2A	Air-entrained	6.0	2-1/2	6.8
3P	Nonair-entrained	7.5	2-1/2	
3A	Air-entrained	7.5	2-1/2	4.3
4P	Nonair-entrained	9.0	2-1/2	
4A	Air-entrained	9.0	2-1/2	5.6
5P	Nonair-entrained	4.5	6	
5A	Air-entrained	4.5	6	3.7
6P	Nonair-entrained	6.0	6	
6A	Air-entrained	6.0	6	5.0
7P	Nonair-entrained	7.5	6	
7A	Air-entrained	7.5	6	3.7
8P	Nonair-entrained	9.0	6	
8A	Air-entrained	9.0	6	4.4

Table 1-Z identifies the test specimens and gives their exposure record through 1966, at which time the exposure was discontinued after 1809 cycles of freezing-and-thawing at Treat Island.

Since the test beams had considerable loss in dimensions during the exposure, the %E values obtained since 1955 are not considered to be a reliable indication of beam condition. Therefore, to assess the results of

this exposure it is necessary to adopt a uniform criteria by which all specimens can be judged.

If a beam is considered as failed when it loses an end, disintegrates, or when the %E drops below 50%, the relative durability of the 16 mixtures can be compared as shown in the following tabulation.

Mixture No.	Beam No.	Average No. of Years of Survival
1P	27066, 27069, 27072	9
1A	27152, 27155, 27158	12+
2P	27075, 27078, 27081	3+
2A	27188, 27191, 27194	9
3P	27085, 27088, 27091	3-
3A	27143, 27146, 27149	9+
4P	27094, 27097, 27104	2
4A	27197, 27200, 27203	6
5P	27107, 27110, 27113	6
5A	27206, 27209, 27212	12
6P	27116, 27119, 27122	2
6A	27170, 27173, 27176	12
7P	27125, 27128, 27131	1
7A	27161, 27164, 27167	9
8P	27134, 27137, 27140	1
8A	27179, 27182, 27185	5+

Findings

The findings of this study are summarized below:

a. Each air-entrained mixture survived from 3 to 10 years longer at Treat Island than its companion nonair-entrained mixture (1A vs 1P, 2A vs 2P, etc.). This demonstrates the beneficial effect of air entrainment in concretes that are subjected to freezing-and-thawing while wet.

b. The order of durability of the air-entrained mixtures, from most durable to least durable, was:

(5A (7A
1A, (6A, 3A, (2A, 4A, 8A

c. The order of durability of the nonair-entrained mixtures, from most durable to least durable, was:

				(4P	(7P
1P,	5P,	2P,	3P,	(6P,	(8P

d. The order of durability of all mixtures, from most durable to least durable, was:

	(5A		(2A	(4A				(4P	(7P
1A,	(6A,	3A,	(7A,	(5P,	8A,	2P,	3P,	(6P,	(8P
			(1P						

e. The order of durability with respect to water-cement ratio (gal/bag), from most to least durable, was:

4.5, 6.0, 7.5, 9

f. The order of durability with respect to slump (in.), from most durable to least durable, was: 2-1/2, 6.

g. If both water-cement ratio and slump (gal/bag and in.) are considered, the order of durability, from most durable to least durable, was:

4.5 and 2-1/2, 4.5 and 6, 6.0 and 6, 6.0 and 2-1/2, 7.5 and 2-1/2, 7.5 and 6, 9.0 and 2-1/2, 9.0 and 6

The results of this exposure were included in a discussion of the results of the overall cooperative program by Mr. D. L. Bloem, National Sand and Gravel Association, in January 1968. This discussion is given in its entirety as Appendix A.

(Issued Sept 1968)

Table 1-Z

Program 20

Mixture Data and Record of Testing of Concrete Beams, Cooperative Study of Air-Entrained Concrete

1951-1966 (Installed November 1951)

Beam No.	Air %	Water-Cement Ratio gal/bag	Slump in.	1951-1962 Readings: 0 Cycles 1951 %E	101 Cycles 1952 %E	186 Cycles 1953 %E	297 Cycles 1954 %E	442 Cycles 1955 %E	609 Cycles 1956 %E	753 Cycles 1957 %E	824 Cycles 1958 %E	974 Cycles 1959 %E	1045 Cycles 1960 %E	1186 Cycles 1961 %E	1275 Cycles 1962 %E
							Nonair-entrained Concrete								
27066	None	4.5	2-1/2	100	107	116	110	104	102	105*	111*	110*	131*	164*	227*
27069				100	108	118	120	126	125	127	130	134	142*	170*	171*
27072				100	109	118	122	126	124	123	126	125	129	127	132
27075	None	6.0	2-1/2	100	106	107	39F**								
27078				100	107	117	43F								
27081				100	107	116	97	38F							
27085	None	7.5	2-1/2	100	93	†									
27088				100	108	62	D††								
27091				100	111	68	D								
27094	None	9.0	2-1/2	100	104	†									
27097				100	81	†									
27104				100	74	†									
27107	None	4.5	6	100	109	117	99	94	94	*	*	*	*	†	
27110				100	105	115	117	115	123	118*	125*	*	*	†	
27113				100	106	115	113	108	116	112*	156*	*	*	†	
27116	None	6.0	6	100	74	†									
27119				100	67	†									
27122				100	70	31F									
27125	None	7.5	6	100	†										
27128				100	†										
27131				100	†										
27134	None	9.0	6	100	†										
27137				100	†										
27140				100	†										
							Air-entrained Concrete								
27143	4.3	7.5	2-1/2	100	110	111	114	117	123	133	132*	138*	138*	144*	152*
27146				100	111	114	118	119	123	129	129	136	130	133	136
27149				100	110	112	116	119	124	131	139	145	156*	172*	187*
27152	3.6	4.5	2-1/2	100	116	119	124	135	136	135	136	139	139	135	134
27155				100	110	113	114	131	129	131	133	133	133	128	132
27158				100	108	111	98	119	124	125	139	124	122	118	109
27161	3.7	7.5	6	100	112	114	118	118	122	129	139	145	148*	182*	165*
27164				100	111	113	118	121	126	131	138	144	144*	141*	152*
27167				100	112	115	117	119	124	127	135	149	154*	152*	178*
27170	5.0	6.0	6	100	111	112	120	117	121	122	122	127	122	113	103
27173				100	112	117	115	124	127	132	139	139	139	133	143
27176				100	111	116	120	123	128	131	135	135	135	136	132
27179	4.4	9.0	6	100	109	111	115	120	129	140*	153*	*	*	†	
27182				100	110	112	114	120	128*	146*	145*	*	*	†	
27185				100	111	113	112	112	116*	117*	93*	*	*	†	
27188	6.8	6.0	2-1/2	100	109	113	116	117	121	124*	126*	129*	126*	126*	132*
27191				100	111	114	115	118	121	137	122	125	125	125	122
27194				100	109	112	116	119	123	126	127	131	*		
27197	5.6	9.0	2-1/2	100	110	112	114	118	123	131*	142*	143*	*	†	
27200				100	111	113	116	120	125	129*	129*	137*	*	†	
27203				100	111	115	123	127	133	142*	159*	168*	142*	147*	150*
27206	3.7	4.5	6	100	111	115	118	121	126	126	129	132	124	127	124
27209				100	109	113	115	119	126	124	127	130	129	129	132
27212				100	110	115	119	122	129	129	131	132	133	133	130

(Continued)

* End gone.
** Specimens marked F failed, and have been discarded.
† Ends gone, discarded.
†† Specimens marked D disintegrated.

Program 20

Table 1-Z (Concluded)

Beam No.	Air %	Water-Cement Ratio gal/bag	Slump in.	1963-1966 Readings: 1381 Cycles 1963 %E	1516 Cycles 1964 %E	1679 Cycles 1965 %E	1809 Cycles 1966 (Final) %E
				Nonair-entrained Concrete			
27066	None	4.5	2-1/2	‡		Disintegrated	
27069				‡		243‡	310‡
27072				135*	‡	Disintegrated	
				Air-entrained Concrete			
27143	4.3	7.5	2-1/2	165‡	165‡	189‡	261‡
27146				130‡	90‡	Disintegrated	
27149				205‡	212‡	156‡	156‡
27152	3.6	4.5	2-1/2	133*	136‡	139‡	139‡
27155				128*	115*	119‡	119‡
27158				115	104*	151‡	143‡
27161	3.7	7.5	6	‡	Gone		
27164				141‡	105‡	Disintegrated	
27167				217‡	230‡	Disintegrated	
27170	5.0	6.0	6	81‡	‡	Disintegrated	
27173				144‡	141‡	165‡	188‡
27176				147‡	144‡	138‡	142‡
27188	6.8	6.0	2-1/2	138*	141‡	144‡	159‡
27191				122‡	128‡	145‡	145‡
27203	5.6	9.0	2-1/2	155‡	160‡	156‡	156‡
27206	3.7	4.5	6	123*	126*	122*	119‡
27209				132*	121‡	130‡	131‡
27212				131*	124‡	118‡	118‡

* End gone.
‡ Ends gone, specimen retained.

Appendix A

Discussion by D. L. Bloem*

on

Significance of Accelerated Durability Tests for Concrete**

This report describes a cooperative program of the Waterways Experiment Station (WES), the Bureau of Public Roads (BPR), and the Joint Research Laboratory (JRL) of the National Sand and Gravel Association (NSGA) and National Ready Mixed Concrete Association. Concrete performance comparisons were made of two laboratory freezing and thawing test methods with a severe field exposure in tidewater. Variables in the concrete were four water-cement ratios at high and low slump, with and without air-entrainment. The same aggregates, consisting of good quality crushed limestone and natural siliceous sand, were used throughout.

A single batch of concrete was made for each of the 16 conditions. Nine 3- by 4- by 16-inch beams were molded from each batch for exposure in triplicate to each of the three freezing and thawing environments. The specimens were fog-cured for 35 days and air-dried for 8 days. After the air-drying period, those for laboratory freezing and thawing were fog-cured for an additional 28 days before test. Those for field exposure were shipped to Treat Island, Maine, and placed in the WES tidewater exposure racks.

The JRL test exposure consisted of alternate freezing in air at 0 F and thawing in water at 40 F in accordance with ASTM Method C 291.[1] At the BPR laboratory, the cycle consisted of freezing to 0 F in water (ice) and thawing to 72 F in water at a rate of one cycle per day. The field exposure at Treat Island is described in a paper by Kennedy and K. Mather[2] as follows:

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** For presentation at Wednesday Morning Session, January 24, 1968, of U. S. - Japan Joint Seminar on Research on Basic Properties of Various Concretes.

> The experimental exposure station at Cobscook Bay, Treat Island, consists of a timber rack at mean-tide elevation attached to a wharf. There are approximately 1500 specimens on the rack. The rack is roofed [roof was removed from rack in September 1963 and will not be replaced] over tc insure that all specimens received a similar exposure by eliminating differences due to sunlight and wind. Specimens placed on the rack are exposed to twice-daily reversals of an average 18-ft tide. At times during the winter months alternate exposure to freezing air and submergence in sea water at approximately 34 F produces frequent and severe cycles of freezing and thawing in the concrete. The temperature of the water is always low, ranging annually from 42 to 30 F, and tends to reduce chemical reactions between concrete and the salts in sea water.
>
> The number of cycles of freezing and thawing as well as intensity of the cycles varies with severity of the winter. Over the past twelve winters [prior to 1953] the average number of cycles of freezing and thawing has been 136 with a high of 242...and low of 89....

Disintegration in the laboratory tests was measured in terms of changes in dynamic modulus of elasticity determined in accordance with ASTM Method C 215.[3] The general criterion of failure was a 50 percent reduction, although exposure for air-entrained concretes in many cases had to be terminated before that level was reached. Failure of the specimens at Treat Island manifested itself by cracking and surface spalling of such magnitude that meaningful measurements of fundamental frequency became impossible.

The data are summarized in table 1. Response to the different freezing and thawing exposures is shown graphically in fig. 1, and relationships among the exposures are indicated in figs. 2 and 3.

Figure 1 shows that, for all exposures, resistance to freezing and thawing decreased as the water-cement ratio increased. The effect was much more pronounced for nonair-entrained than for air-entrained concrete. In the laboratory exposures, air-entrainment produced very large improvements

in resistance. In the field, air-entrainment had a much smaller effect ranging from almost none for the lowest water-cement ratio to substantial for the higher water-cement ratios.

There was a slight trend toward lower durability for the high-slump concretes in comparison with their low-slump counterparts but, with one exception (nonair-entrained concretes in the field exposure), the difference was not large nor consistent.

It is evident from fig. 1 that the two laboratory cycles differ in severity and that their ability to predict endurance in the field is different for air-entrained than for nonair-entrained concrete. On a cycle-for-cycle basis, both laboratory test methods were much more destructive to nonair-entrained concrete than field exposure. For the air-entrained concrete, however, the JRL laboratory cycle was much less severe than the field exposure while the BPR laboratory cycle was somewhat more severe.

Approximate relations of field endurance to the laboratory test cycles are shown in figs. 2 and 3. For nonair-entrained concretes, the number of freezing and thawing cycles in tidewater which the specimens withstood can be expressed fairly well as a multiple of the number of laboratory cycles survived, thus: For the JRL cycle,

$$F = 10L_A$$

and, for the BPR cycle,

$$F = 23L_B$$

where

F = number of cycles of tidewater freezing and thawing survived,

L_A = number of JRL laboratory cycles survived,

L_B = number of BPR laboratory cycles survived.

Even more roughly, exponential functions can be fitted to the data for air-entrained concrete, as follows:

$$F = 10L_A^{0.57} \text{ for the JRL cycle,}$$

and

$$F = 10L_B^{0.8} \text{ for the BPR cycle.}$$

In summary, the tests showed that laboratory freezing and thawing did provide a relative measure of the ability of various concretes to withstand a particular, highly severe outdoor exposure. The relation of field endurance to laboratory test results was different for air-entrained than for nonair-entrained concrete. The benefits of air-entrainment were not as impressive in the field exposure as was indicated by the laboratory tests.

The BPR cycle, where freezing and thawing both were in water, perhaps correlated slightly better with field performance than the JRL rapid cycle of freezing in air and thawing in water. It is quite possible that this advantage would not exist for correlations with other field environments where the concrete is not continuously saturated. The BPR test produced failure in fewer cycles but required about 10 times as long to generate the same number of cycles as the JRL method.

References

1. American Society for Testing and Materials, "Standard Method of Test for Resistance of Concrete Specimens to Rapid Freezing in Air and Thawing in Water," Designation: C 291-67, 1967 Book of ASTM Standards, Part 10, 1967, Philadelphia, Pa.

2. Kennedy, T. B. and Mather, K., "Correlation Between Laboratory Accelerated Freezing and Thawing and Weathering at Treat Island, Maine," Proceedings, American Concrete Institute, Vol 50, Oct 1953, pp 141-172.

3. American Society for Testing and Materials, "Standard Method of Test for Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens," Designation: C 215-60, 1967 Book of ASTM Standards, Part 10, 1967, Philadelphia, Pa.

Table 1. Comparison Between Laboratory and Field Exposures of Concretes With Varied Properties

Each test represents average for three 3- by 4- by 16-in. beams molded from a single batch of concrete for the given condition.

Mix No.	Water-Cement Ratio by wt.	Cement, lb. per cubic yard	Sand, percent total agg.	Air Content, per-cent	Laboratory F. & T. Cycles to 50% E NSGA(1)	BPR(2)	Survival in Tidal Exposure at Treat Island Years	Cycles
Nonair-entrained concrete, 2-1/2-inch slump								
1	0.40	780	44	(3)	89	45	9	1045
2	0.53	600	46	(3)	38	11	3+	330
3	0.67	470	47	(3)	15	7	3-	260
4	0.80	415	49	(3)	8	7	2	186
Nonair-entrained concrete, 6-inch slump								
5	0.40	830	43	(3)	73	45	6	753
6	0.53	680	44	(3)	40	15	2	186
7	0.67	545	45	(3)	11	4	1	101
8	0.80	490	47	(3)	6	4	1	101
Air-entrained concrete, 2-1/2-inch slump								
9	0.40	815	41	3.6	3690	415*	12+	1410
10	0.53	535	43	6.8	(4)	415*	9	1045
11	0.67	460	44	4.3	4500*	240*	9+	1080
12	0.80	375	46	5.6	3800*	255*	6	753
Air-entrained concrete, 6-inch slump								
13	0.40	865	41	3.7	(4)	555*	12	1381
14	0.53	590	43	5.0	(4)	455*	12	1381
15	0.67	490	44	3.7	3220	230*	9	1045
16	0.80	405	46	4.4	1600	200	5+	645

(1) Freezing in air at 0 F and thawing in water at 40 F per ASTM Method C 291, Test for Resistance to Rapid Freezing in Air and Thawing in Water.
(2) Freezing in water to 0 F and thawing in water at 72 F at rate of one cycle per day.
(3) Air not measured; estimated at 1 to 1.5 percent.
* Values extrapolated; test terminated at smaller number of cycles.
(4) Specimens essentially undamaged after 4000 cycles when test was terminated.

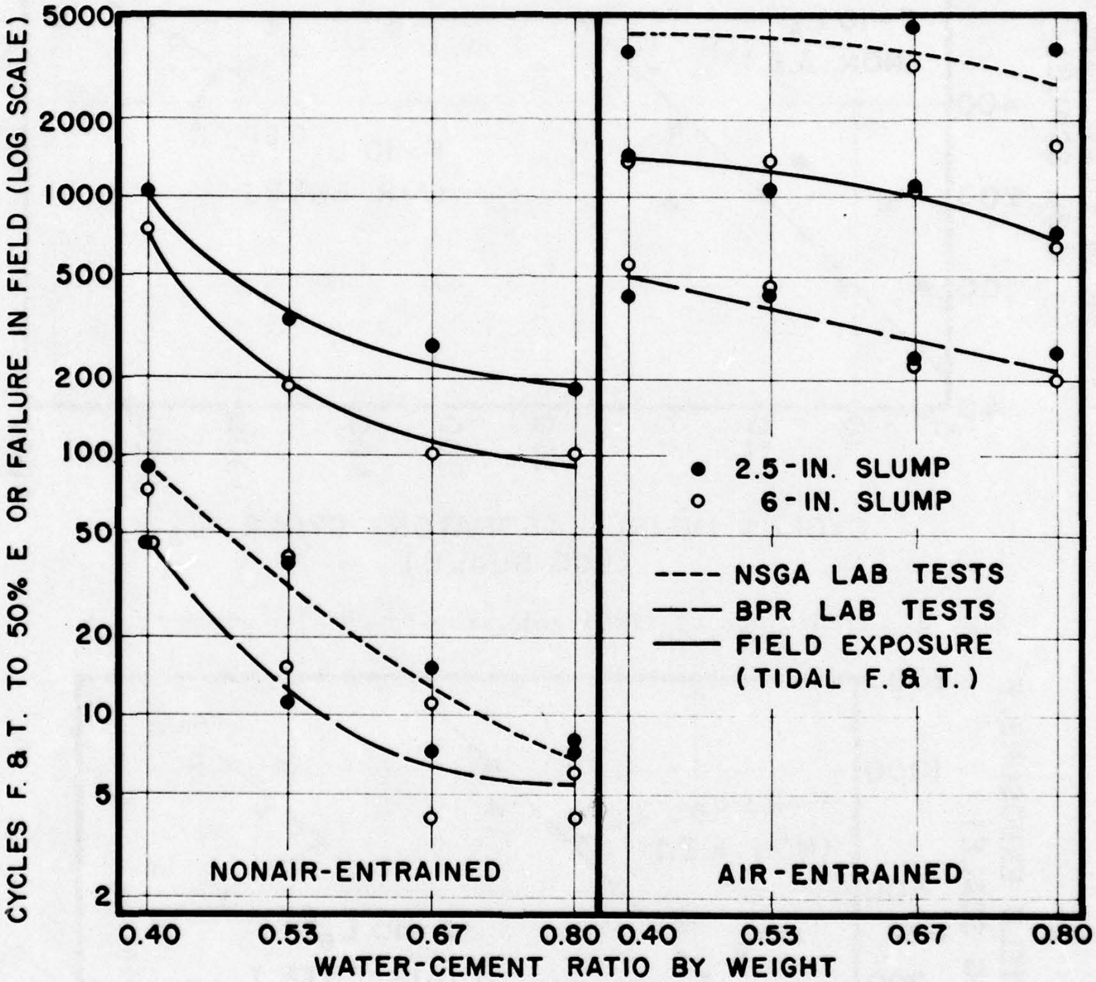

Fig. 1. Effect of water-cement ratio on resistance of concrete to freezing and thawing in the laboratory or in the field

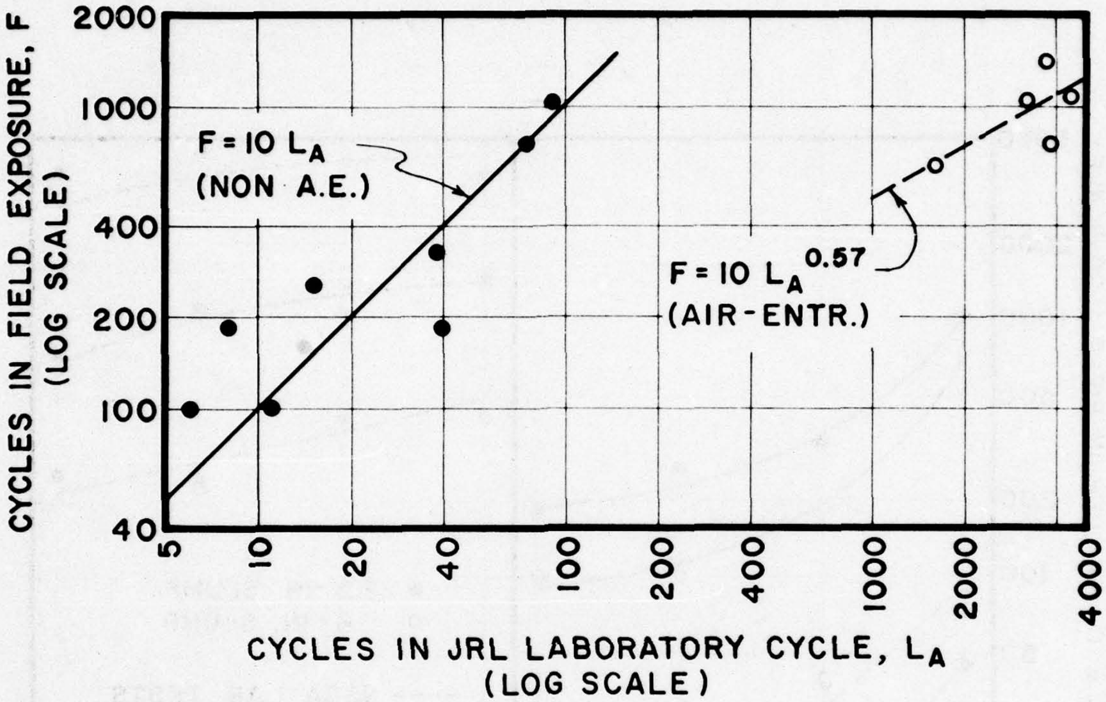

Fig. 2. Prediction of field endurance by JRL laboratory test

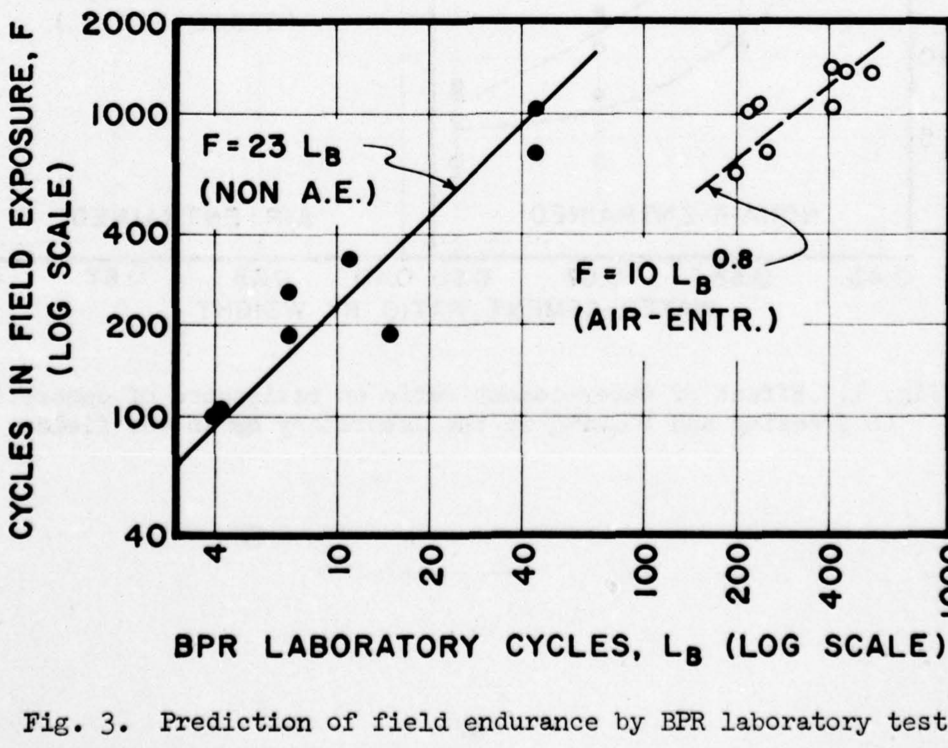

Fig. 3. Prediction of field endurance by BPR laboratory test

Cement Durability Program*

The cement durability program was begun in 1939 to develop data for use in preparing an acceptance specification for portland cement that would provide greater assurance of durability in concrete exposed to severe weathering. A total of 52 samples of portland cement and clinker were collected from 47 mills widely distributed throughout the United States. The determination of field durability was conducted at several exposure stations, with specimens exposed at various times.

Treat Island Installations

First installation

The first installation on the Treat Island exposure rack consisted of 276 concrete columns** (6 by 6 by 48 in.), which were installed on the following dates:

Date	No. of Specimens
October 1940	271
January 1941	5

Four to six specimens represented each of the 52 cements. All of these specimens were made from concrete of the same basic mixture: water-cement ratio, 6.0 gal per bag; cement factor, 5.1 bags per cu yd. The aggregates consisted of siliceous sand and gravel.

Six of the 52 cements were "treated" cements; i.e., they contained a material such as resin, tallow, or oil as an addition to the cement. In the fall of 1943, after exposure to 511 cycles of freezing-and-thawing, six (treated cement) specimens were returned to the laboratory for compression and flexure tests. The results are given on the following page.

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* See: Corps of Engineers, Central Concrete Laboratory, Cement Durability Program, First Interim Report (June 1942).
__________, Concrete Research, Second Interim Report, Part I. "Laboratory studies of concrete containing air-entraining admixtures" (July 1945).

** Columns are molded with their long axis in a vertical position; beams are molded with their long axis in a horizontal position.

Column No.	Cement Designation	Cement Type	Age days	Relative Strength* Flexural	Relative Strength* Compressive
E-3-G	C	I w/tallow	1278	81	112
E-12-G	M	II w/oil	1248	103	100
E-32-G	EE	I w/tallow	1201	85	127
E-39-G	KK	II + resin	1189	86	119
E-60-G	ZZ	Resin	1156	73	140
E-61-G	AZ	Special	1154	87	117

* In percent of 28-day strength.

The specimens containing the different cements reacted differently in the laboratory strength tests, but in general, there is evidence of mild retrogression in flexural strength and equality or gain in compressive strength.

Table 1-CRE lists the specimens in this installation, and gives their exposure record along with the cements used in each. This exposure was terminated in 1969 after 3776 cycles of freezing-and-thawing. The average durability of the specimens made from each of the 52 cements can be compared as shown in the following tabulation.

Specimens Containing Cement	Average No. of Years of Survival (Approximate)
M	26
C	20
ZZ	16
EE	15
KK	13
AZ	6
The 40 other cements	<2

Test specimens made with the treated cements (M, C, ZZ, EE, KK, and AZ) had an average survival of from 6 to 26 years whereas test specimens made with the 40 untreated cements had an average survival of less than 2 years.

Second installation

The second installation consisted of 37 concrete columns (6 by 6 by

48 in.), which were installed on the Treat Island exposure rack on the following dates:

Date	No. of Specimens
June 1941	12
October 1941	25

These columns represented 37 (one specimen per cement) of the original 52 cements. The specimens were made at the same time and from the same basic mix as those in the first installation, and had been exposed out-of-doors at West Point, New York, in the interim. Table 1-CRE also lists these specimens, the cements in each, and gives their exposure record through 1969 when the exposure was terminated.

Four of the 37 cements represented in this installation were treated cements used in the first installation, and the other 33 were untreated cements used in the first installation.

The average durabilities obtained on this group of specimens are given below:

Specimens Containing Cement	Average No. of Years of Survival (Approximate)
C	28
M	27
KK	>22
EE	>7
The 33 other cements	<2

Test specimens made with the 33 untreated cements had an average survival of less than 2 years, whereas those made with the treated cements had an average survival of from 7+ to 28 years.

Third installation

The third installation consisted of 48 concrete columns (6 by 6 by 48 in.), which were installed on the Treat Island exposure rack in October 1942. These specimens represented 12 of the original 52 cements, and the cements used came from the original samples. The purpose of this

installation was to study the effect on the durability of concrete of using four different types of aggregate with some of the original cements. The four types of aggregate used were: limestone, dolomite, round gravel, and traprock.

The concrete containing limestone, dolomite, or traprock had a water-cement ratio of 6.0 gal per bag and a cement factor of 6.75 bags per cu yd; the concrete containing round gravel aggregate had the same water-cement ratio, but a cement factor of 6.25 bags per cu yd. Table 2-CRE lists these specimens, their cements and aggregates, and gives their exposure record through 1969, at which time the exposure was terminated.

Three of the 12 cements represented in this installation were "treated" cements and the other nine were untreated cements. Specimens made with five of the untreated cements (O, GG, JJ, TT, and XX) demonstrated practically no resistance to the weathering; their average survival was only 1 year or less. Average survivals of specimens made with cements R, W, NN, and WW (all untreated) were 6+, 13, 17, and 7 years, respectively. Specimens made with cements EE, KK, and ZZ (the treated cements) had average survivals of 27, 13, and 27 years, respectively. The following tabulation gives the relative durabilities with respect to the four aggregates used.

Cement	No. of Years of Survival (Approximate)			
	Limestone	Dolomite	Round Gravel	Traprock
O	1	0	--	1
R	1	1	--	18
W	--	15	10	14
EE (treated)	--	22	--	27
GG	1	1	1	0
JJ	0	0	1	0
KK (treated)	4	13	22	--
NN	6	22	16	25
TT	0	0	--	0
WW	4	10 (avg of 2)	--	--
XX	0	0	0	0
ZZ (treated)	--	--	--	27

The most durable mixture appears to be a treated cement (either EE or ZZ) with a traprock aggregate. Limestone aggregate concrete has the poorest durability in this exposure, with the durability of specimens containing dolomite being a little greater than those containing round gravel. Traprock is apparently the most durable aggregate.

St. Augustine Installation

In order that the influence of sea water on concrete might be determined without the added effects of freezing-and-thawing, and in particular its possible influence on the durability of the specimens located at Treat Island, 152 concrete columns (6 by 6 by 48 in.) were installed on the mild-weathering exposure rack at St. Augustine, Florida, in November 1940. These specimens were similar to those installed at Treat Island in 1940, i.e. same basic mixture and same aggregates. Fifty-one of the original 52 cements were represented in this installation (two or three specimens per cement). Table 3-CRE lists these specimens, their cements, and gives their exposure record through 1970, at which time the exposure was terminated.

In the summer of 1956, three columns were returned to the laboratory for petrographic examination. These three columns, E-6-H, E-9-H, and E-32-H, had broken during the exposure and it was desired to determine the reason for their breakage. The findings of the laboratory examination were:

a. Columns E-6-H and E-9-H showed no evidence of deteriorative processes so the breakage of these specimens might have been due to damage incurred during handling.

b. Column E-32-H, made with a high-alkali, high C_3A cement (cement EE, Type I with tallow) was determined to have failed due to alkali-aggregate reaction and concurrent deterioration due to sulfate attack. This was one of the first examples of alkali-aggregate reaction involving natural aggregate A.

After 30 years of exposure at St. Augustine, only nine columns have failed. A list of these columns is given on the following page.

Column No.	Cement	Approximate C_3A Content of Cement, %
E-3-E	C (Type I with tallow)	13.3
E-3-K		13.3
E-24-H	Y (Type I)	7.1
E-32-E	EE (Type I with tallow)	13.7
E-32-H		13.7
E-32-K		13.7
E-58-E	YY (high C_3A)	17.4
E-58-H		17.4
E-58-K		17.4

Eight of the nine columns that failed were made with cements having a C_3A content of more than 13 percent, and these cements (C, EE, and YY) were the only cements used in this installation which had C_3A contents greater than 13 percent. This suggests that the failures were due to the high C_3A content; this conclusion is borne out by the findings of the 1956 laboratory examination of column E-32-H.

Column E-24-H was made with a cement whose C_3A content was only about 7 percent; although this column is listed as failed, it could have been broken in handling during cleaning operations. Therefore, not much significance is attached to the "failure" of this column.

Other Installations

An additional 208 specimens representing the 52 cements were fabricated and installed in 1940 in groups of three at the moderate weathering exposure station (West Point, New York, and later at Mt. Vernon, New York), and singly at the nonweathering exposure station (West Point, New York, and later at Mt. Vernon, New York). These specimens were tested periodically. Except for slight localized surface crazing, the specimens remained sound and all but one had relative moduli of elasticity above 100 percent of the initial moduli after 6 years exposure; the other specimen had a relative modulus in excess of 90 percent. Since no differences had been noted between specimens representing different cements, and since the laboratory

was being moved to the Waterways Experiment Station, these exposure stations were discontinued and the specimens were discarded in 1946.

Findings

The findings of this investigation were:

a. Concrete specimens made with untreated cements exhibited low resistance to the tidal freezing-and-thawing at Treat Island. Forty-six of the 52 cements tested were untreated cements.

b. Concrete specimens made with treated cements exhibited good to extraordinary durability in the Treat Island exposure. The six treated cements which were used were (in order, maximum to minimum durability): Cements M, C, ZZ, KK, EE, AZ. Each of these cements contained a saponifiable material such as resin, tallow, or oil, and because of this treatment could be classified as an air-entraining cement, which accounts for the remarkable durability.

c. The durability of concrete specimens at Treat Island with respect to aggregates is in the following order, maximum to minimum durability: Traprock, dolomite, round gravel, limestone.

d. Concrete specimens made with the three cements containing more than 13 percent C_3A exhibited poor durability at St. Augustine. These three cements were (in order, maximum to minimum durability): C, EE, YY.

e. One concrete specimen made with cement Y was broken in the St. Augustine exposure; this breakage is believed to be due to handling rather than to deteriorative processes.

f. Concrete specimens made with the remaining cements have exhibited good durability in the St. Augustine exposure.

(Revised Sept 1970)

Table 1-CRE

Program 21

Record of Testing of Columns, Containing 52 Cements, for Durability at Treat Island

1940-1970 (Installed 1940 and 1941)

Long Arm, Row 1 (E to W)

		1940-1952 Readings												
Spec No.	Cement Type and Designation*	0 Cycles Oct 1940 %E	157 Cycles 1941 %E	323 Cycles 1942 %E	511 Cycles 1943 %E	653 Cycles 1944 %E	763 Cycles 1945 %E	868 Cycles 1946 %E	986 Cycles 1947 %E	1117 Cycles 1948 %E	1222 Cycles 1949 %E	1383 Cycles 1950 %E	1472 Cycles 1951 %E	1573 Cycles 1952 %E
						First Installation (Oct 1940)								
E-1-C	II, A	100	Failed											
E-1-D		100	Failed											
E-1-G		100	Failed											
E-1-J		100	Failed											
E-1-M		100	Failed											
E-2-D	II, B	100	Failed											
E-2-G		100	Failed											
E-2-J		100	Failed											
E-2-M		100	Failed											
E-2-O		100	Failed											
E-3-D	I w/tallow,	100	117	114	116	119	126	128	132	123	123	125	129	130
E-3-G	C	100	113	114	115-Returned to laboratory in Oct 1943									
E-3-J		100	118	118	119	122	129	130	135	127	126	128	131	133
E-3-O		100	116	115	116	118	124	127	132	122	124	125	128	130
E-4-D	II, D	100	Failed											
E-4-G		100	Failed											
E-4-J		100	Failed											
E-4-M		100	Failed											
E-4-O		100	Failed											
E-5-D	II, E	100	95	Failed										
E-5-G		100	Failed											
E-5-J		100	79	Failed										
E-5-M		100	112	Failed										
E-5-O		100	127	Failed										
E-6-D	II, F	100	89	Failed										
E-6-G		100	Failed											
E-6-J		100	89	Failed										
E-6-M		100	89	Failed										
E-6-O		100	89	Failed										
E-7-D	II, G	100	Failed											
E-7-G		100	Failed											
E-7-J		100	Failed											
E-7-M		100	Failed											
E-7-O		100	Failed											
E-8-D	II, H	100	Failed											
E-8-G		100	Failed											
E-8-J		100	Failed											
E-8-M		100	Failed											
E-8-O		100	Failed											
E-9-D	II modified, J	100	63	Failed										
E-9-G		100	65	Failed										
E-9-J		100	96	Failed										
E-9-M		100	94	Failed										
E-9-O		100	104	Failed										
E-10-D	Low C_3A, K	100	Failed											
E-10-G		100	Failed											
E-10-J		100	Failed											
E-10-M		100	Failed											
E-10-O		100	Failed											
E-11-D	II, L	100	Failed											
E-11-G		100	Failed											
E-11-J		100	Failed											
E-11-M		100	Failed											
E-11-O		100	Failed											
E-12-D	II w/oil,	100	118	120	120	120	124	130	134	132	133	131	135	141
E-12-G	M	100	120	116	117-Returned to laboratory Oct 1943									
E-12-J		100	125	126	125	126	129	138	145	138	137	138	141	143
E-12-M		100	120	118	120	123	127	134	142	133	133	135	139	141
E-12-O		100	119	116	120	122	124	136	143	135	136	137	143	149

(Continued)

* The 52 cements used are designated A through H, J through U, W through Z, AA through HH, JJ through UU, WW through ZZ, and AZ, BY, CX, DW.

Program 21 (Revised Sept 1970)

Table 1-CRE (Continued)

Spec No.	Cement Type and Designa-tion	0 Cycles Oct 1940 %E	157 Cycles 1941 %E	323 Cycles 1942 %E	511 Cycles 1943 %E	653 Cycles 1944 %E	763 Cycles 1945 %E	868 Cycles 1946 %E	986 Cycles 1947 %E	1117 Cycles 1948 %E	1222 Cycles 1949 %E	1383 Cycles 1950 %E	1472 Cycles 1951 %E	1573 Cycles 1952 %E
		1940-1952 Readings												
		First Installation (Oct 1940) (Continued)												
E-13-D	II, N	100	58	Failed										
E-13-G		100	Failed											
E-13-J		100	87	Failed										
E-13-M		100	104	54	Failed									
E-13-O		100	105	55	Failed									
E-14-D	II, O	100	Failed											
E-14-G		100	Failed											
E-14-J		100	Failed											
E-14-M		100	Failed											
E-14-O		100	Failed											
E-15-D	II approx, P	100	Failed											
E-15-G		100	Failed											
E-15-J		100	Failed											
E-15-L		100	Failed											
E-15-M		100	Failed											
E-16-D	II, Q	100	Failed											
E-16-G		100	Failed											
E-16-J		100	Failed											
E-16-M		100	Failed											
E-16-O		100	Failed											
E-17-D	II, R	100	53	Failed										
E-17-G		100	Failed											
E-17-J		100	Failed											
E-17-M		100	64	Failed										
E-17-O		100	89	71	Failed									
E-18-D	Similar to II, S	100	Failed											
E-18-G		100	Failed											
E-18-J		100	Failed											
E-18-M		100	Failed											
E-18-O		100	Failed											
E-19-D	II, T	100	Failed											
E-19-G		100	Failed											
E-19-J		100	Failed											
E-19-M		100	Failed											
E-19-O		100	Failed											
E-20-D	II modi-fied, U	100	Failed											
E-20-G		100	Failed											
E-20-J		100	Failed											
E-20-M		100	Failed											
E-20-O		100	Failed											
E-22-D	I, W	100	118	Failed										
E-22-G		100	Failed											
E-22-J		100	106	Failed										
E-22-M		100	114	70	Failed									
E-22-O		100	117	78	Failed									
E-23-D	II, X	100	Failed											
E-23-G		100	Failed											
E-23-J		100	Failed											
E-23-M		100	67	Failed										
E-23-O		100	Failed											
E-24-D	I, Y	100	Failed											
E-24-G		100	Failed											
E-24-J		100	Failed											
E-24-M		100	Failed											
E-24-O		100	Failed											
E-25-D	II, Z	100	Failed											
E-25-G		100	Failed											
E-25-J		100	Failed											
E-25-M		100	Failed											
E-25-O		100	Failed											
E-26-D	II, AA	100	100	Failed										
E-26-G		100	Failed											
E-26-J		100	99	Failed										
E-26-M		100	100	Failed										
E-26-O		100	106	Failed										

(Continued)

(Revised Sept 1970)

Table 1-CRE (Continued)

Program 21

Spec No.	Cement Type and Designation	0 Cycles Oct 1940 %E	157 Cycles 1941 %E	323 Cycles 1942 %E	511 Cycles 1943 %E	653 Cycles 1944 %E	763 Cycles 1945 %E	868 Cycles 1946 %E	986 Cycles 1947 %E	1117 Cycles 1948 %E	1222 Cycles 1949 %E	1383 Cycles 1950 %E	1472 Cycles 1951 %E	1573 Cycles 1952 %E
		1940-1952 Readings												
		First Installation (Oct 1940) (Continued)												
E-27-D	II, BB	100	107	Failed										
E-27-G		100	Failed											
E-27-J		100	108	Failed										
E-27-M		100	109	Failed										
E-27-O		100	110	74	Failed									
E-28-D	II, CC	100	Failed											
E-28-G		100	Failed											
E-28-J		100	Failed											
E-28-M		100	Failed											
E-28-O		100	Failed											
E-31-D	II approx, DD	100	Failed											
E-31-G		100	Failed											
E-31-J		100	Failed											
E-31-M		100	Failed											
E-31-O		100	Failed											
E-32-D	I w/tallow, EE	100	137	131	138	139	143	150	156	147	146	148	151	153
E-32-G		100	141	136	139-Returned to laboratory Oct 1943									
E-32-J		100	146	143	145	146	152	159	164	155	154	155	159	161
E-32-M		100	133	132	136	135	141	143	150	150	Broken in handling			
E-32-O		100	133	129	133	135	141	143	147	139	137	139	160	Failed
E-33-D	I, FF	100	Failed											
E-33-G		100	Failed											
E-33-J		100	Failed											
E-33-M		100	Failed											
E-33-O		100	Failed											
E-36-D	II approx, GG	100	Failed											
E-36-G		100	Failed											
E-36-J		100	Failed											
E-36-M		100	Failed											
E-36-O		100	Failed											
E-37-D	II, HH	100	Failed											
E-37-G		100	Failed											
E-37-J		100	Failed											
E-37-M		100	Failed											
E-37-O		100	Failed											
E-38-D	II approx, JJ	100	Failed											
E-38-F		100	Failed											
E-38-G		100	Failed											
E-38-J		100	Failed											
E-38-M		100	Failed											
E-38-O		100	Failed											
E-39-D	II approx + resin, KK	100	105	108	109	112	115	116	121	114	110	**	107	105
E-39-F		100	106	109	111	112	118	120	123	114	108	97	97	84
E-39-G		100	112	112	115-Returned to laboratory Oct 1943									
E-39-J		100	105	108	109	113	118	120	124	107	113	99	100	97
E-39-M		100	103	109	113	114	120	123	128	119	117	112	112	110
E-39-O		100	104	107	108	101	105	106	105	102	94	**	88	87
E-40-D	II approx, LL	100	Failed											
E-40-F		100	105	Failed										
E-40-G		100	Failed											
E-40-J		100	Failed											
E-40-M		100	90	Failed										
E-40-O		100	101	Failed										
E-41-F	I approx, MM	100	Failed											
E-41-G		100	Failed											
E-41-J		100	Failed											
E-41-M		100	Failed											
E-41-O		100	Failed											
E-42-D	II, NN	100	111	89	Failed									
E-42-F		100	Failed											
E-42-G		100	112	73	Failed									
E-42-J		100	111	62	Failed									
E-42-M		100	110	70	Failed									
E-42-O		100	115	82	Failed									

(Continued)

** Spurious sonic readings were obtained on these specimens in 1950.

(Revised Sept 1970)

Program 21

Table 1-CRE (Continued)

Spec No.	Cement Type and Designation	0 Cycles Oct 1940 %E	157 Cycles 1941 %E	323 Cycles 1942 %E	511 Cycles 1943 %E	653 Cycles 1944 %E	763 Cycles 1945 %E	868 Cycles 1946 %E	986 Cycles 1947 %E	1117 Cycles 1948 %E	1222 Cycles 1949 %E	1383 Cycles 1950 %E	1472 Cycles 1951 %E	1573 Cycles 1952 %E
		1940-1952 Readings												
		First Installation (Oct 1940) (Continued)												
E-43-D	II, OO	100	106	Failed										
E-43-F		100	Failed											
E-43-G		100	110	Failed										
E-43-J		100	111	Failed										
E-43-M		100	113	Failed										
E-43-O		100	109	Failed										
E-44-D	II, PP	100	Failed											
E-44-F		100	Failed											
E-44-G		100	Failed											
E-44-J		100	Failed											
E-44-M		100	Failed											
E-44-O		100	Failed											
E-45-D	II, QQ	100	Failed											
E-45-F		100	78	Failed										
E-45-G		100	Failed											
E-45-J		100	88	Failed										
E-45-M		100	76	Failed										
E-45-O		100	96	Failed										
E-46-D	II, RR	100	109	Failed										
E-46-F		100	Failed											
E-46-G		100	95	Failed										
E-46-J		100	109	Failed										
E-46-M		100	111	68	Failed									
E-46-O		100	112	68	Failed									
E-47-D	II, SS	100	51	Failed										
E-47-F		100	84	Failed										
E-47-G		100	Failed											
E-47-J		100	Failed											
E-47-M		100	Failed											
E-47-O		100	Failed											
E-51-D	II, TT	100	Failed											
E-51-F		100	Failed											
E-51-G		100	Failed											
E-51-J		100	Failed											
E-51-M		100	Failed											
E-51-O		100	Failed											
E-53-D	II, UU	100	116	Failed										
E-53-F		100	121	Failed										
E-53-G		100	119	Failed										
E-53-J		100	118	Failed										
E-53-M		100	114	Failed										
E-53-O		100	Failed											
E-56-D	II, WW	100	59	Failed										
E-56-F		100	81	Failed										
E-56-G		100	Failed											
E-56-J		100	84	Failed										
E-56-M		100	Failed											
E-56-O		100	Failed											
E-57-D	II, XX	100	Failed											
E-57-F		100	Failed											
E-57-G		100	Failed											
E-57-J		100	Failed											
E-57-M		100	Failed											
E-57-O		100	Failed											
E-58-D	High C_3A, YY	100	104	Failed										
E-58-F		100	116	Failed										
E-58-G		100	Failed											
E-58-J		100	115	Failed										
E-58-M		100	Failed											
E-58-O		100	Failed											
E-60-D	Resin, ZZ	100	114	116	118	119	126	126	130	120	119	117	115	115
E-60-F		100	112	111	113	115	122	125	130	122	121	122-Broken in handling		
E-60-G		100	114	116	118-Returned to laboratory Oct 1943									
E-60-J		100	127	127	127	128	135	137	140	128	127	124	123	123
E-60-M		100	111	113	113	115	121	122	124	111	111	106	110	108
E-60-O		100	114	115	117	121	126	126	128	118	118	113	116	114

(Continued)

(Revised Sept 1970)

Table 1-CRE (Continued)

Program 21

Spec No.	Cement Type and Designation	0 Cycles Oct 1940 %E	157 Cycles 1941 %E	323 Cycles 1942 %E	511 Cycles 1943 %E	653 Cycles 1944 %E	763 Cycles 1945 %E	868 Cycles 1946 %E	986 Cycles 1947 %E	1117 Cycles 1948 %E	1222 Cycles 1949 %E	1383 Cycles 1950 %E	1472 Cycles 1951 %E	1573 Cycles 1952 %E
		1940-1952 Readings												
		First Installation (Oct 1940) (Continued)												
E-61-D	Special,	100	117	117	117	115	116	116	115	109	Failed			
E-61-F	AZ	100	113	111	113	111	118	119	125	130	Failed			
E-61-G		100	119	117	117-Returned to laboratory Oct 1943									
E-61-J		100	121	121	120	119	121	123	125	Failed				
E-61-M		100	119	120	118	117	120	124	131	Failed				
E-61-O		100	118	121	117	113	114	116	115	Failed				
E-62-F	II, BY	100	Failed											
E-62-G		100	110	Failed										
E-62-J		100	113	Failed										
E-62-M		100	117	Failed										
E-62-O		100	113	Failed										
E-63-D	I, CX	100	Failed											
E-63-F		100	Failed											
E-63-G		100	Failed											
E-63-J		100	Failed											
E-63-M		100	Failed											
E-63-O		100	Failed											

Spec No.	Cement Type and Designation	1658 Cycles 1953 %E	1658 Cycles 1953 Pulse Veloc fps	1658 Cycles 1953 %V²	1769 Cycles 1954 %E	1769 Cycles 1954 %V²	1914 Cycles 1955 %E	1914 Cycles 1955 %V²	2081 Cycles 1956 %E	2081 Cycles 1956 %V²	2225 Cycles 1957 %E	2225 Cycles 1957 %V²	2296 Cycles 1958 %E	2296 Cycles 1958 %V²	2446 Cycles 1959 %E	2446 Cycles 1959 %V²	2517 Cycles 1960 %E	2517 Cycles 1960 %V²	2658 Cycles 1961 %E	2658 Cycles 1961 %V²
		1953-1961 Readings																		
		First Installation (Oct 1940)																		
E-3-D	I	136	15,095	100	144	92	148	90	148	89	191	--	216	--	220	--	Fail.			
E-3-J	w/tallow,	137	14,600	100	146	95	146	94	151	101	156	93	164	93	152	88	156	--	Fail.	
E-3-O	C	133	14,545	100	141	99	144	96	148	100	155	93	159	94	148	90	152	92	156	--
E-12-D	II w/oil,	140	15,875	100	151	95	154	94	160	98	132	93	101	94	128	--	125	--	122	--
E-12-J	M	143	15,810	100	151	89	156	86	164	--	125	--	128	--	95	--	95	--	100	--
E-12-M		144	--	--	163	--	177	--	155	--	171	--	187	--	185	--	193	--	190	--
E-12-O		154	--	--	171	--	187	--	149	--	141	--	130	--	90	--	92	--	92	--
E-32-D	I	151	14,705	100	160	94	153	89	147	--	127	--	133	--	Fail.					
E-32-J	w/tallow, EE	159	14,545	100	172	96	166	97	172	91	164	90	151	--	200		Fail.			
E-39-D	II approx	105	--	--	105	--	105	--	Fail.											
E-39-F	+ resin,	Fail.																		
E-39-J	KK	Fail.																		
E-39-M		113	--	--	111	--	94	--	98	--	79	--	Fail.							
E-39-O		Fail.																		
E-60-D	Resin,	115	13,935	100	112	95	98	89	98	83	81	75	Fail.							
E-60-J	ZZ	121	13,515	100	123	93	100	86	92	--	Fail									
E-60-M		100	13,560	100	105	97	83	90	75	--	75	--	69	--	Fail.					
E-60-O		106	13,890	100	111	96	89	87	82	92	82	66	54	--	Fail.					

Exposure Rack, Row 2 (W to E)

Spec No.	Cement Type and Designation	2747 Cycles 1962 %E	2747 Cycles 1962 %V²	2853 Cycles 1963 %E	2853 Cycles 1963 %V²	2988 Cycles 1964 %E	2988 Cycles 1964 %V²	3151 Cycles 1965 %E	3151 Cycles 1965 %V²	3281 Cycles 1966 %E	3281 Cycles 1966 %V²	3437 Cycles 1967 %E	3437 Cycles 1967 %V²	3622 Cycles 1968 %E	3622 Cycles 1968 %V²	3776 Cycles 1969 %E	3776 Cycles 1969 %V²
		1962-1969 Readings															
		First Installation (Oct 1940)															
E-3-O	I w/tallow, C	156	--	160	--	Broken in handling											
E-12-D	II w/oil,	122	--	119	--	114	--	96	--	103	--	103	--	96	--	Fail.	--
E-12-J	M	105	--	97	--	108	--	140	--	180	--	173	--	Fail.	--		
E-12-M		190	--	190	--	162	--	180	--	203	--	206	--	Fail.	--		
E-12-O		88	--	Fail.													

-- Dashed lines in "Pulse Veloc" or "%V²" columns indicate that a pulse velocity reading was not taken because of the roughness of the ends of the specimens.

Table 1-CRE (Continued)

Spec No.	Cement Type and Designation	0 Cycles Jan 1941 %E	85 Cycles Oct 1941 %E	251 Cycles 1942 %E	438 Cycles 1943 %E	581 Cycles 1944 %E	691 Cycles 1945 %E	796 Cycles 1946 %E	914 Cycles 1947 %E	1045 Cycles 1948 %E	Cycles 1949 %E	Cycles 1950 %E	Cycles 1951 %E	Cycles 1952 %E
		1941-1952 Readings												
		First Installation (Jan 1941)												
E-64-C	II, DW	100	88	Failed										
E-64-D		100	121	Failed										
E-64-F		100	107	107	84	Failed								
E-64-G		100	Failed											
E-64-J		100	149	Failed										

Spec No.	Cement Type and Designation	0 Cycles June 1941 %E	0 Cycles Oct 1941 %E	166 Cycles 1942 %E	353 Cycles 1943 %E	496 Cycles 1944 %E	606 Cycles 1945 %E	711 Cycles 1946 %E	829 Cycles 1947 %E	960 Cycles 1948 %E	1065 Cycles 1949 %E	1226 Cycles 1950 %E	1315 Cycles 1951 %E	1416 Cycles 1952 %E
		1941-1952 Readings												
		Second Installation (June 1941 and Oct 1941)												
E-1-A	II, A	100	109	Failed										
E-2-A	II, B	100	109	Failed										
E-3-A	I w/tallow, C		100	108	115	118	124	128	134	125	125	127	132	132
E-4-A	II, D	100	119	Failed										
E-5-A	II, E	100	112	91	Failed									
E-6-A	II, F	100	109	Failed										
E-7-A	II, G	100	107	Failed										
E-8-A	II, H	100	107	78	Failed									
E-9-A	II modified, J		100	Failed										
E-10-A	Low C_3A, K		100	Failed										
E-11A	II, L	100	117	Failed										
E-12-A	II w/oil, M		100	112	116	119	128	132	138	131	130	133	138	139
E-13-A	II, N		100	Failed										
E-14-A	II, O		100	Failed										
E-15-C	II approx, P		100	Failed										
E-16-C	II, Q		100	Failed										
E-18-A	Similar to II, S		100	Failed										
E-19-C	II, T		100	Failed										
E-20-C	II modified, U		100	Failed										
E-22-A	I, W		100	Failed										
E-24-C	I, Y		100	Failed										
E-25-C	II, Z		100	Failed										
E-27-A	II, BB	100	116	69	Failed									
E-28-C	II, CC		100	Failed										
E-31-C	II approx, DD		100	Failed										
E-32-A	I w/tallow, EE		100	94	101	102	111	113	117	118	Broken in handling			
E-33-A	I, FF		100	Failed										
E-36-A	II approx, GG	100	127	Failed										
E-37-C	II, HH		100	Failed										
E-38-A	II approx, JJ		100	Failed										
E-39-A	II approx + resin, KK		100	106	110	120	118	122	126	120	120	122	125	127
E-41-C	I approx, MM		100	Failed										
E-42-C	II, NN	100	122	77	Failed									
E-43-C	II, OO		100	Failed										
E-44-A	II, PP		100	Failed										
E-46-A	II, RR	100	137	Failed										
E-47-C	II, SS		100	Failed										

(Continued)

(Revised Sept 1970)

Table 1-CRE (Concluded)

Program 21

Exposure Rack, Row 1 (W to E)

Spec No.	Cement Type and Designation	1953-1961 Readings: 1501 Cycles 1953 %E	1501 Cycles 1953 Pulse Veloc fps	1501 Cycles 1953 %V²	1612 Cycles 1954 %E	1612 Cycles 1954 %V²	1757 Cycles 1955 %E	1757 Cycles 1955 %V²	1924 Cycles 1956 %E	1924 Cycles 1956 %V²	2068 Cycles 1957 %E	2068 Cycles 1957 %V²	2139 Cycles 1958 %E	2139 Cycles 1958 %V²	2289 Cycles 1959 %E	2289 Cycles 1959 %V²	2360 Cycles 1960 %E	2360 Cycles 1960 %V²	2501 Cycles 1961 %E	2501 Cycles 1961 %V²
Second Installation (June 1941 and Oct 1941) (Continued)																				
E-3-A	I w/tallow, C	137	15,265	100	145	91	145	90	151	93	154	90	158	91	154	85	150	86	154	--
E-12-A	II w/oil, M	140	15,565	100	149	99	154	96	160	101	131	94	203	98	129	91	126	93	123	90
E-39-A	II approx + resin, KK	128	14,650	100	145	96	139	94	145	90	137	92	144	92	130	--	127	--	111	--

Exposure Rack, Row 2 (W to E)

Spec No.	Cement Type and Designation	1962-1969 Readings: 2590 Cycles 1962 %E	2590 Cycles 1962 %V²	2696 Cycles 1963 %E	2696 Cycles 1963 %V²	2831 Cycles 1964 %E	2831 Cycles 1964 %V²	2994 Cycles 1965 %E	2994 Cycles 1965 %V²	3124 Cycles 1966 %E	3124 Cycles 1966 %V²	3280 Cycles 1967 %E	3280 Cycles 1967 %V²	3465 Cycles 1968 %E	3465 Cycles 1968 %V²	3619 Cycles 1969 %E	3619 Cycles 1969 %V²
Second Installation (June 1941 and Oct 1941)																	
E-3-A	I w/tallow, C	154	--	158	--	147	--	151	--	162	--	162	--	162	--	133	--
E-12-A	II w/oil, M	123	--	120	--	103	--	100	--	105	--	100	--	97	--	Fail.	
E-39-A	II approx + resin, KK	111	--	102	--	Broken in handling											

-- Dashed lines in "%V²" column indicate that end of specimen was too rough to obtain satisfactory pulse velocity reading.

(Revised Sept 1970)

Table 2-CRE

Program 21

Record of Testing of Concrete Columns, Containing 12 Cements and 4 Aggregates, for Durability at Treat Island

1942-1970 (Third Installation, Oct 1942)

Long Arm, Row 1 (E to W)

Spec No.	Cement Type and Designation	Type Aggregate	0 Cycles 1942 %E	187 Cycles 1943 %E	330 Cycles 1944 %E	440 Cycles 1945 %E	545 Cycles 1946 %E	663 Cycles 1947 %E	794 Cycles 1948 %E	899 Cycles 1949 %E	1060 Cycles 1950 %E	1149 Cycles 1951 %E	1250 Cycles 1952 %E
			1942-1952 Readings										
E-14-W	II, O	Limestone	100	79	Failed								
E-14-X		Dolomite	100	Failed									
E-14-Y		Round gravel	Broken at installation										
E-14-Z		Traprock	100	82	Failed								
E-17-W	II, R	Limestone	100	98	Failed								
E-17-X		Dolomite	100	95	Failed								
E-17-Y		Round gravel	Broken at installation										
E-17-Z		Traprock	100	106	109	112	118	125	115	115	84	117	118
E-22-W	I, W	Limestone	Broken at installation										
E-22-X		Dolomite	100	104	111	105	111	125	109	104	95	104	91
E-22-Y		Round gravel	100	105	109	110	115	122	105	105	105	76	62
E-22-Z		Traprock	100	107	112	113	121	128	117	117	116	114	108
E-32-W	I	Limestone	Broken at installation										
E-32-X	w/tallow,	Dolomite	100	111	115	121	122	125	114	111	109	110	108
E-32-Y	EE	Round gravel	Broken at installation										
E-32-Z		Traprock	100	111	115	123	124	127	121	109	119	121	121
E-36-W	II approx,	Limestone	100	113	Failed								
E-36-X	GG	Dolomite	100	109	Failed								
E-36-Y		Round gravel	100	100	Failed								
E-36-Z		Traprock	100	Failed									
E-38-W	II approx,	Limestone	100	Failed									
E-38-X	JJ	Dolomite	100	Failed									
E-38-Y		Round gravel	100	61	Failed								
E-38-Z		Traprock	100	Failed									
E-39-W	II approx	Limestone	100	103	107	96	96	Failed					
E-39-X	+ resin,	Dolomite	100	108	113	115	114	115	113	112	112	112	114
E-39-Y	KK	Round gravel	100	109	116	122	124	125	118	115	112	110	110
E-42-W	II, NN	Limestone	100	102	110	113	115	128	120	Failed			
E-42-X		Dolomite	100	104	111	115	118	122	108	107	106	106	108
E-42-Y		Round gravel	100	105	111	118	119	122	108	112	108	109	106
E-42-Z		Traprock	100	102	107	115	115	128	114	112	112	113	115
E-51-W	II, TT	Limestone	100	Failed									
E-51-X		Dolomite	100	Failed									
E-51-Y		Round gravel	Broken at installation										
E-51-Z		Traprock	100	Failed									
E-56-W	II, WW	Limestone	100	87	96	99	90	Failed					
E-56-X1		Dolomite	100	108	112	116	119	122	111	109	108	107	111
E-56-X2		Dolomite	100	101	Failed								
E-56-Y		Round gravel	Broken at installation										
E-56-Z		Traprock	Broken at installation										
E-57-W	II, XX	Limestone	100	Failed									
E-57-X		Dolomite	100	Failed									
E-57-Y		Round gravel	100	Failed									
E-57-Z		Traprock	100	Failed									
E-60-W	Resin,	Limestone	Broken at installation										
E-60-X	ZZ	Dolomite	Broken at installation										
E-60-Y		Round gravel	Broken at installation										
E-60-Z		Traprock	100	107	110	116	119	124	116	114	114	115	116

(Continued)

(Revised Sept 1970)

Program 21

Table 2-CRE (Concluded)

Exposure Rack, Row 1 (W to E)

Spec No.	Cement Type and Designation	Type Aggregate	1953-1959 Readings: 1335 Cycles, 1953 %E	Pulse Veloc fps	%V^2	1446 Cycles 1954 %E	%V^2	1591 Cycles 1955 %E	%V^2	1758 Cycles 1956 %E	%V^2	1902 Cycles 1957 %E	%V^2	1973 Cycles 1958 %E	%V^2	2123 Cycles 1959 %E	%V^2
E-17-Z	II, R	Traprock	121	15,875	100	128	98	132	--	136	--	136	--	138	--	101	--
E-22-X	I, W	Dolomite	77	16,600	100	81	--	80	--	72	87	72	--	Fail.			
E-22-Y		Round gravel	Fail.														
E-22-Z		Traprock	105	16,195	100	93	85	74	--	58	--	Fail.					
E-32-X	I	Dolomite	109	14,980	100	113	94	110	92	113	96	109	--	115	--	103	--
E-32-Z	w/tallow, EE	Traprock	125	14,600	100	127	94	129	95	130	94	126	95	133	94	126	90
E-39-X	II approx	Dolomite	116	--	--	117	--	118	--	Fail.							
E-39-Y	+ resin, KK	Round gravel	111	14,185	100	113	98	109	95	115	97	108	92	114	92	101	84
E-42-X	II, NN	Dolomite	109	15,265	100	113	103	112	93	117	97	105	--	105	--	105	--
E-42-Y		Round gravel	106	15,445	100	100	92	88	81	88	--	68	--	68	--	Fail.	
E-42-Z		Traprock	117	16,600	100	121	94	120	95	122	65	122	89	129	92	114	87
E-56-X1	II, WW	Dolomite	111	16,805	100	117	94	116	94	120	94	110	--	113	--	94	--
E-60-Z	Resin, ZZ	Traprock	119	15,265	100	124	96	124	94	127	95	124	94	130	95	114	92

Exposure Rack, Row 2 (W to E)

Spec No.	Cement Type and Designation	Type Aggregate	1960-1967 Readings: 2194 Cycles 1960 %E	%V^2	2335 Cycles 1961 %E	%V^2	2424 Cycles 1962 %E	%V^2	2530 Cycles 1963 %E	%V^2	2665 Cycles 1964 %E	%V^2	2828 Cycles 1965 %E	%V^2	2958 Cycles 1966 %E	%V^2	3114 Cycles 1967 %E	%V^2
E-17-Z	II, R	Traprock	101	--	Fail.													
E-32-X	I	Dolomite	97	--	94	--	91	--	66	--	57	--	Failed					
E-32-Z	w/tallow, EE	Traprock	123	93	123	--	116	--	116	--	116	--	116	--	110	--	110	--
E-39-Y	II approx + resin, KK	Round gravel	98	--	101	--	101	--	98	--	Broken in handling							
E-42-X	II, NN	Dolomite	105	--	105	--	97	--	81	--	60	--	Failed					
E-42-Z		Traprock	114	91	114	--	108	--	94	--	89	--	82	--	95	--	90	--
E-56-X1	II, WW	Dolomite	89	--	89	--	Fail.											
E-60-Z	Resin, ZZ	Traprock	117	93	117	95	114	93	108	91	108	93	108	80	129	80	126	--

Exposure Rack, Row 2 (W to E)

Spec No.	Cement Type and Designation	Type Aggregate	1968- 1969 Readings: 3299 Cycles 1968 %E	%V^2	3453 Cycles 1969 %E	%V^2
E-32-Z	I w/tallow, EE	Traprock	116	--	100	--
E-42-Z	II, NN	Traprock	Failed	--		
E-60-Z	Resin, ZZ	Traprock	114	--	117	--

-- Dashed lines in "%V^2" column indicate that end of specimen was too rough to obtain satisfactory pulse reading. (Sheet 2)

(Revised Sept 1970)

Table 3-CRE

Program 21

Record of Testing of Columns Containing 51 Cements at St. Augustine

1940-1970 (Installed November 1940)

		1940-1960 Readings															
Spec No.	Cement Type and Designation	1940 %E	1942 %E	1944 %E	1946 %E	1948 %E	1950 %E	1952 %E	1954 %E	1954 Pulse Veloc fps	1954 $\%V^2$	1956 %E	1956 $\%V^2$	1958 %E	1958 $\%V^2$	1960 %E	1960 $\%V^2$
E-1-E	II, A	100	114	119	120	118	118	112	110	16,530	100	113	85	108	92	111	91
E-1-H		100	113	119	122	116	117	105	110	16,325	100	108	85	108	90	111	95
E-1-K		100	112	120	126	118	118	112	112	16,325	100	109	85	106	91	106	94
E-2-E	II, B	100	112	121	120	123	123	114	117	16,460	100	117	87	112	90	117	92
E-2-H		100	111	119	121	119	117	114	111	16,530	100	112	87	102	90	109	93
E-2-K		100	111	119	123	118	118	115	111	16,460	100	113	97	110	90	113	92
E-3-E	I w/tallow,	100	115	120	Fail.												
E-3-H	C	100	113	119	118	109	129	103	103	14,600	100	106	86	98	94	101	73
E-3-K		100	115	120	115	89	Fail.										
E-4-E	II, D	100	112	115	118	112	110	112	104	16,195	100	105	88	107	94	105	95
E-4-H		100	115	117	119	116	115	110	110	16,260	100	108	90	110	93	110	95
E-4-K		100	108	110	112	111	118	107	107	16,600	100	107	87	105	92	105	91
E-5-E	II, E	100	114	120	124	121	122	118	118	16,460	100	120	86	115	89	115	92
E-5-H		100	119	124	125	121	122	123	120	16,395	100	123	85	118	89	118	91
E-5-K		100	115	120	124	121	121	117	114	16,325	100	120	86	115	91	112	92
E-6-E	II, F	100	114	120	119	120	121	115	118	16,325	100	116	87	113	90	110	93
E-6-H		100	115	122	122	111	Broken - Returned to laboratory in 1956										
E-6-K		100	112	116	126	123	120	119	114	16,460	100	120	84	117	89	114	90
E-7-E	II, G	100	117	125	132	129	123	125	120	16,735	100	125	86	122	91	114	93
E-7-H		100	112	120	126	117	Broken in handling										
E-7-K		100	113	123	Broken in handling												
E-8-E	II, H	100	115	124	129	124	121	121	115	16,665	100	120	86	117	89	112	93
E-8-H		100	111	120	127	117	120	114	118	16,805	100	115	87	110	91	113	92
E-8-K		100	115	119	121	122	125	116	111	16,600	100	111	89	114	91	109	94
E-9-E	II modi-	100	114	117	122	Broken in handling											
E-9-H	fied, J	100	117	124	131	105	Broken - Returned to laboratory in 1956										
E-9-K		100	113	120	121	127	118	117	114	16,880	100	112	90	112	88	109	91
E-10-E	Low C_3A,	100	119	131	138	126	126	133	127	16,880	100	127	92	124	88	121	91
E-10-H	K	100	117	126	131	136	122	124	121	16,325	100	133	90	130	94	124	96
E-10-K		100	122	134	139	125	134	134	134	16,000	100	136	93	130	97	124	101
E-11-E	II, L	100	115	120	127	Broken in handling											
E-11-H		100	117	124	127	Broken in handling											
E-11-K		100	116	121	123	123	123	119	116	16,395	100	116	89	124	91	113	94
E-12-E	II w/oil,	100	115	122	123	123	122	112	114	15,565	100	111	87	122	93	111	93
E-12-H	M	100	125	128	133	126	127	120	123	15,325	100	120	89	129	93	117	95
E-12-K		100	120	123	126	126	121	118	117	15,445	100	117	90	128	93	114	94
E-13-E	II, N	100	113	123	121	122	116	117	117	16,130	100	114	89	125	92	114	95
E-13-H		100	112	121	Broken in handling												
E-13-K		100	108	118	122	124	121	116	116	16,395	100	116	87	127	92	114	97
E-14-E	II, O	100	111	117	118	117	118	113	103	16,325	100	99	87	119	94	109	97
E-14-H		100	124	128	130	135	130	124	121	16,130	100	117	87	144	92	120	97
E-14-K		100	118	124	126	136	125	127	128	16,460	100	122	90	142	91	125	96
E-15-E	II approx,	100	125	132	138	136	133	130	127	16,195	100	124	87	148	90	124	96
E-15-H	P	100	125	132	137	133	133	129	130	16,130	100	130	90	148	92	130	97
E-15-K		100	117	122	127	127	124	118	118	16,195	100	121	90	141	90	116	95
E-16-E	II, Q	100	119	127	132	132	132	124	123	16,530	100	126	87	149	89	123	94
E-16-H		100	122	130	132	132	130	124	121	16,195	100	124	90	147	93	121	95
E-16-K		100	115	124	125	137	122	120	118	16,260	100	118	89	137	92	113	96
E-17-E	II, R	100	116	122	125	124	121	115	116	16,195	100	116	88	136	92	111	95
E-17-H		100	114	121	127	120	119	112	114	16,065	100	112	90	134	92	115	99
E-17-K		100	117	123	130	130	123	126	126	15,875	100	120	91	140	95	117	99
E-18-E	Similar to	100	131	143	153	151	147	141	144	16,065	100	141	96	168	94	141	99
E-18-H	II, S	100	126	133	143	141	140	130	135	16,325	100	135	90	160	92	130	96
E-18-K		100	124	132	139	138	135	131	132	16,195	100	132	91	160	94	130	97

(Continued)

(Revised Sept 1970)

Table 3-CRE (Continued)

Spec No.	Cement Type and Designation	1940 %E	1942 %E	1944 %E	1946 %E	1948 %E	1950 %E	1952 %E	1954 %E	1954 Pulse Veloc fps	1954 $\%V^2$	1956 %E	1956 $\%V^2$	1958 %E	1958 $\%V^2$	1960 %E	1960 $\%V^2$
		1940-1960 Readings															
E-19-E	II, T	100	119	123	129	125	123	123	118	15,810	100	118	89	151	94	121	97
E-19-H		100	119	124	124	125	125	120	123	15,935	100	123	90	150	94	123	98
E-19-K		100	117	122	121	125	124	116	113	15,875	100	122	90	149	95	119	98
E-20-E	II modified, U	100	110	116	128	122	121	119	112	16,195	100	118	91	143	92	121	97
E-20-H		100	118	126	136	131	129	125	119	16,130	100	122	90	151	92	122	97
E-20-K		100	123	131	136	144	140	131	131	16,000	100	136	99	158	94	130	98
E-22-E	I, W	100	111	114	119	117	118	111	116	16,600	100	119	84	114	90	106	93
E-22-H		100	119	123	124	129	120	117	120	16,735	100	120	84	115	90	115	92
E-22-K		100	114	117	123	122	123	119	116	16,805	100	119	83	114	89	111	91
E-23-E	II, X	100	123	134	136	135	133	130	128	17,020	100	129	83	123	89	120	90
E-23-H		100	130	140	141	141	135	135	133	17,020	100	137	81	131	90	128	90
E-23-K		100	130	142	145	141	133	133	124	17,240	100	127	79	121	88	124	88
E-24-E	I, Y	100	119	121	119	112	108	113	116	16,325	100	113	82	116	92	113	92
E-24-H		100	123	Fail.													
E-24-K		100	112	114	110	104	105	105	104	16,195	100	107	82	102	90	102	91
E-25-E	II, Z	100	127	131	138	137	135	132	128	16,530	100	128	83	125	91	125	91
E-25-H		100	123	133	142	145	135	139	134	16,600	100	131	85	128	91	128	90
E-25-K		100	122	131	Broken in handling												
E-26-E	II, AA	100	115	118	119	122	117	113	108	16,735	100	111	81	103	91	103	91
E-26-H		100	115	118	116	116	115	108	107	16,665	100	110	83	102	90	104	91
E-26-K		100	114	117	118	121	120	113	114	16,805	100	117	81	107	90	105	90
E-27-E	II, BB	100	119	124	128	125	126	121	120	16,950	100	118	83	115	92	112	91
E-27-H		100	122	128	131	134	132	126	122	17,095	100	122	81	119	90	122	88
E-27-K		100	116	122	125	126	121	117	113	16,735	100	115	85	110	90	110	92
E-28-E	II, CC	100	118	123	127	126	119	120	113	16,665	100	118	84	110	90	110	91
E-28-H		100	113	118	120	121	119	112	106	16,735	100	106	85	101	91	103	91
E-28-K		100	114	118	119	120	113	110	110	16,530	100	110	85	103	91	108	91
E-31-E	II approx, DD	100	116	118	123	125	117	112	111	16,665	100	117	83	107	89	110	89
E-31-H		100	117	121	124	131	120	117	114	16,600	100	117	85	114	91	119	89
E-31-K		100	114	118	118	120	112	112	109	16,260	100	112	86	102	93	107	93
E-32-E	I w/tallow, EE	100	124	126	125	Fail.											
E-32-H		100	127	128	126	Fail. - Returned to laboratory in 1956											
E-32-K		100	127	128	128	Fail.											
E-33-E	I, FF	100	119	122	124	121	126	124	123	16,325	100	126	86	120	93	131	92
E-33-H		100	119	121	123	118	123	115	112	16,460	100	117	83	109	92	120	92
E-33-K		100	116	119	120	114	114	109	109	16,395	100	114	83	106	91	119	91
E-36-E	II approx, GG	100	125	132	Broken in handling												
E-36-H		100	118	126	130	Broken in handling											
E-36-K		100	113	121	120	123	106	109	111	16,195	100	111	86	124	92	108	93
E-37-E	II, HH	100	133	140	145	148	146	138	141	16,065	100	141	88	161	90	138	94
E-37-H		100	124	129	132	139	134	124	118	16,130	100	122	84	131	89	Brkn in hdlg	
E-37-K		100	125	130	133	128	131	117	114	16,000	100	118	87	148	90	126	92
E-38-E	II approx, JJ	100	115	120	117	120	121	109	106	16,395	100	106	86	124	90	103	94
E-38-H		100	115	121	119	110	112	103	100	16,325	100	112	85	131	91	107	94
E-38-K		100	112	118	116	112	111	107	107	16,130	100	102	84	120	92	102	91
E-39-E	II approx + resin, KK	100	116	121	120	117	113	104	102	14,495	100	94	84	108	89	89	92
E-39-H		100	116	121	119	121	109	104	102	14,495	100	102	82	116	89	93	90
E-39-K		100	117	121	120	114	115	106	103	14,815	100	103	84	114	90	95	89
E-40-E	II approx, LL	100	112	117	127	116	114	112	109	16,195	100	110	85	135	90	108	91
E-40-H		100	112	115	125	117	118	113	115	16,325	100	112	83	131	89	109	90
E-40-K		100	111	114	125	114	119	115	109	16,260	100	111	84	135	89	106	92
E-41-E	I approx, MM	100	116	119	120	119	117	112	105	16,325	100	105	83	123	87	107	90
E-41-H		100	114	117	115	118	118	113	106	16,195	100	112	83	131	88	107	89
E-41-K		100	110	114	111	114	112	109	106	16,130	100	105	84	126	88	103	90
E-42-E	II, NN	100	121	125	128	125	116	113	110	16,395	100	88	80	Broken in handling			
E-42-H		100	121	126	134	133	126	120	118	16,325	100	118	85	138	89	115	91
E-42-K		100	121	127	134	130	128	125	115	16,395	100	118	85	144	86	112	90
E-43-E	II, OO	100	113	117	119	121	114	Broken in handling									
E-43-H		100	113	116	Broken in handling												
E-43-K		100	115	118	118	117	108	106	102	16,325	100	102	77	125	89	102	92

(Continued)

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Table 3-CRE (Continued) Program 21

		1940-1960 Readings															
									1954			1956		1958		1960	
Spec No.	Cement Type and Designation	1940 %E	1942 %E	1944 %E	1946 %E	1948 %E	1950 %E	1952 %E	%E	Pulse Veloc fps	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$
E-44-E	II, PP	100	114	118	116	118	110	106	105	16,130	100	105	84	129	93	105	92
E-44-H		100	112	117	115	116	110	109	102	16,065	100	105	85	129	93	105	92
E-44-K		100	109	112	Broken in handling												
E-45-E	II, QQ	100	114	120	109	115	110	109	101	16,000	100	104	88	128	95	109	92
E-45-H		100	112	118	119	120	114	118	113	16,195	100	115	87	143	90	112	91
E-45-K		100	114	121	122	127	121	116	112	16,065	100	118	89	146	91	115	92
E-46-E	II, RR	100	112	116	125	121	121	116	112	16,665	100	113	85	108	94	121	93
E-46-H		100	114	121	126	124	121	115	115	16,395	100	115	86	110	94	123	94
E-46-K		100	114	121	120	122	120	113	114	16,325	100	114	85	109	93	119	94
E-47-E	II, SS	100	120	125	131	126	125	118	118	16,600	100	115	83	112	91	120	92
E-47-H		100	120	127	136	120	119	113	11[illegible]	16,460	100	115	82	110	89	121	92
E-47-K		100	117	123	121	122	114	116	114	16,665	100	112	83	112	90	125	91
E-51-E	II, TT	100	127	132	133	127	124	120	126	15,875	100	123	85	123	85	132	93
E-51-H		100	131	133	134	124	130	124	124	16,130	100	121	82	121	82	133	92
E-51-K		100	128	131	131	121	121	118	118	15,875	100	121	83	121	83	130	95
E-53-E	II, UU	100	122	127	126	128	124	122	119	16,460	100	122	82	122	82	129	92
E-53-H		100	122	126	126	132	131	124	120	16,600	100	123	81	123	81	132	91
E-53-K		100	122	127	127	128	125	121	123	16,395	100	123	83	123	83	132	91
E-56-E	II, WW	100	120	126	124	Broken in handling											
E-56-H		100	125	133	129	134	131	127	125	16,805	100	125	83	125	83	136	92
E-56-K		100	120	130	126	128	128	125	118	16,600	100	118	83	118	83	135	93
E-57-E	II, XX	100	125	132	132	133	135	124	126	16,325	100	126	85	118	92	135	92
E-57-H		100	132	140	143	147	142	140	138	16,530	100	138	84	129	89	135	90
E-57-K		100	137	143	138	138	143	126	127	16,130	100	130	82	127	91	130	92
E-58-E	High C_3A,	100	118	80	Fail												
E-58-H	YY	100	117	*	Fail												
E-58-K		100	121	97	Fail												
E-60-E	Resin, ZZ	100	124	128	122	123	118	112	102	13,890	100	104	82	101	90	101	89
E-60-H		100	124	128	122	126	107	107	120	13,795	100	101	83	101	89	89	89
E-60-K		100	125	130	129	123	118	109	97	13,700	100	100	83	97	92	Bkn in hdlg	
E-61-E	Special,	100	164	125	128	Broken in handling											
E-61-H	AZ	This specimen was broken prior to installation															
E-61-K		100	169	124	131	121	117	106	100	13,605	100	100	82	91	85	91	95
E-62-E	II, BY	100	120	127	Broken in handling												
E-62-H		100	122	130	134	133	127	122	119	16,735	100	121	82	118	87	121	91
E-62-K		100	119	121	130	128	120	117	111	16,530	100	114	83	109	88	112	91
E-63-E	I, CX	100	121	127	130	135	141	123	118	16,950	100	121	83	118	86	121	91
E-63-H		100	123	127	134	133	132	121	113	16,805	100	116	81	121	86	118	91
E-63-K		100	126	130	135	136	135	122	119	17,020	100	119	81	116	86	124	91
E-64	II, DW	No specimens made with this cement were installed at this station															

		1962-1970 Readings									
		1962		1964		1966		1968		1970	
		%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$	%E	$\%V^2$
E-1-E	II, A	101	95	111	85	108	97	108	90	105	87
E-1-H		101	94	109	86	109	98	109	92	109	90
E-1-K		96	94	103	87	103	104	101	90	99	91
E-2-E	II, B	102	94	117	89	112	101	112	91	117	90
E-2-H		109	94	109	88	107	103	105	90	105	90
E-2-K		100	94	107	89	107	104	105	90	105	87
E-3-H	I w/tallow, C	93	94	101	87	101	98	101	89	115	90
E-4-E	II, D	105	98	113	90	113	101	118	93	113	91
E-4-H		100	97	110	91	110	101	110	95	107	92
E-4-K		93	95	107	89	107	99	107	91	107	91

* This specimen would not respond to flexural vibration.

Table 3-CRE (Continued)

Spec No.	Cement Type and Designation	1962 %E	1962 %V^2	1964 %E	1964 %V^2	1966 %E	1966 %V^2	1968 %E	1968 %V^2	1970 %E	1970 %V^2
		1962-1970 Readings									
E-5-E	II, E	102	93	117	87	114	97	117	89	120	91
E-5-H		105	92	121	86	121	95	118	88	113	88
E-5-K		102	93	115	88	112	97	115	91	118	89
E-6-E	II, F	105	96	115	89	112	94	109	92	112	90
E-6-K		103	94	119	87	116	100	113	88	113	88
E-7-E	II, G	111	97	119	86	119	100	122	90	122	89
E-8-E	II, H	107	96	117	88	114	97	111	93	111	89
E-8-H		101	95	121	88	116	97	111	91	114	89
E-8-K		102	98	117	89	114	98	111	92	114	93
E-9-K	II modified, J	102	93	115	85	112	91	112	89	112	86
E-10-E	Low C_3A, K	113	94	133	84	130	95	130	90	130	90
E-10-H		113	97	133	90	130	101	133	95	136	94
E-10-K		113	102	133	96	130	106	136	100	142	98
E-11-K	II, L	103	100	116	92	116	101	111	92	111	95
E-12-E	II w/oil, M	101	98	114	92	111	104	108	92	108	94
E-12-H		106	99	123	93	117	103	117	93	117	95
E-12-K		106	102	122	93	116	103	113	96	110	95
E-13-E	II, N	104	99	117	92	114	104	109	93	109	91
E-13-K		104	99	117	93	117	103	109	94	94	85
E-14-E	II, O	99	100	109	92	112	104	109	95	109	96
E-14-H		114	99	128	92	128	106	122	94	122	98
E-14-K		111	100	119	93	116	102	113	94	113	94
E-15-E	II approx, P	113	98	133	90	133	101	130	94	130	95
E-15-H		113	99	130	91	130	104	124	94	124	94
E-15-K		103	98	121	91	118	102	113	93	108	91
E-16-E	II, Q	107	97	129	89	126	99	115	92	110	90
E-16-H		108	101	127	92	113	105	116	94	116	93
E-16-K		103	100	121	91	116	103	111	94	106	92
E-17-E	II, R	106	101	117	91	117	102	114	94	111	92
E-17-H		102	102	120	93	117	107	114	95	111	93
E-17-K		106	102	122	93	117	105	112	97	112	97
E-18-E	Similar to II, S	125	104	141	95	141	105	135	96	129	94
E-18-H		116	101	133	93	130	102	133	93	133	93
E-18-K		116	102	133	94	130	105	124	96	124	93
E-19-E	II, T	110	102	127	93	127	105	121	97	121	97
E-19-H		112	102	129	93	126	103	120	95	120	94
E-19-K		111	103	125	94	125	104	119	95	119	96
E-20-E	II modified, U	105	101	121	91	121	103	116	94	111	93
E-20-H		111	102	125	92	125	104	128	93	128	94
E-20-K		116	101	133	93	130	104	130	94	130	95
E-22-E	I, W	99	95	117	89	112	94	109	90	112	87
E-22-H		112	94	126	88	120	96	109	89	109	90
E-22-K		106	91	119	85	119	94	119	86	119	89
E-23-E	II, X	109	94	128	87	120	93	115	88	115	88
E-23-H		116	93	133	87	130	94	124	89	127	87
E-23-K		118	91	132	85	129	90	129	85	132	84
E-24-E	I, Y	110	95	121	90	115	96	115	91	115	94
E-24-K		97	95	110	86	105	106	108	87	108	89
E-25-E	II, Z	116	96	136	89	130	104	118	89	118	90
E-25-H		119	95	140	87	134	111	128	88	128	89
E-26-E	II, AA	98	93	110	89	105	104	100	89	105	87
E-26-H		99	94	111	89	106	106	104	90	109	88
E-26-K		100	95	113	88	110	104	100	88	102	85

(Continued)

Spec No.	Cement Type and Designation	1962 %E	1962 %V^2	1964 %E	1964 %V^2	1966 %E	1966 %V^2	1968 %E	1968 %V^2	1970 %E	1970 %V^2
		1962-1970 Readings									
E-27-E	II, BB	104	94	119	89	116	104	116	89	119	87
E-27-H		111	92	127	88	124	101	113	87	116	86
E-27-K		100	94	112	89	107	106	105	87	110	88
E-28-E	II, CC	103	94	116	89	113	106	113	89	113	89
E-28-H		96	93	108	88	106	108	99	89	99	87
E-28-K		96	94	111	89	108	110	103	88	105	86
E-31-E	II approx, DD	105	94	121	88	116	109	119	90	122	89
E-31-H		108	93	121	89	116	110	116	89	119	89
E-31-K		100	99	113	92	108	109	113	90	113	89
E-33-E	I, FF	114	96	131	92	128	109	120	92	120	90
E-33-H		107	94	120	90	117	107	112	90	112	90
E-33-K		101	94	117	90	114	108	119	90	116	88
E-36-K	II approx, GG	105	99	110	89	107	102	105	94	105	90
E-37-E	II, HH	145	98	145	91	142	104	142	93	139	91
E-37-K		123	97	129	87	129	101	126	92	120	89
E-38-E	II approx, JJ	105	100	105	88	103	103	108	96	108	90
E-38-H		107	100	107	89	110	106	113	90	113	88
E-38-K		102	98	104	88	102	103	102	91	102	88
E-39-E	II approx + resin, KK	92	97	106	85	98	54	109	90	98	86
E-39-H		96	94	99	84	96	53	88	91	69	87
E-39-K		95	98	98	87	101	96	106	89	112	86
E-40-E	II approx, LL	111	100	114	88	117	104	120	92	123	90
E-40-H		109	97	117	86	112	99	122	89	122	89
E-40-K		111	98	111	87	108	100	108	91	106	89
E-41-E	I approx, MM	102	94	Bkn in hdlg							
E-41-H		104	95	109	85	109	99	106	89	106	88
E-41-K		103	97	103	88	105	98	105	90	105	88
E-42-H	II, NN	120	96	120	86	120	102	123	89	123	87
E-42-K		115	95	118	84	115	101	121	89	115	85
E-43-K	II, OO	102	95	102	86	102	100	100	89	95	83
E-44-E	II, PP	108	98	111	86	108	105	105	93	105	91
E-44-H		102	97	107	88	104	102	104	94	99	87
E-45-E	II, QQ	104	99	104	90	107	102	112	94	97	84
E-45-H		115	97	115	88	118	101	118	93	118	90
E-45-K		115	99	120	85	117	101	117	92	112	86
E-46-E	II, RR	111	94	116	87	116	110	111	87	111	90
E-46-H		112	97	117	89	112	108	107	90	107	92
E-46-K		114	95	117	89	114	114	109	91	106	91
E-47-E	II, SS	112	94	117	89	117	109	109	89	106	88
E-47-H		110	94	113	88	110	112	107	88	102	88
E-47-K		112	94	112	87	112	107	107	88	107	88
E-51-E	II, TT	123	95	123	90	123	98	120	94	117	94
E-51-H		121	94	124	88	127	97	121	88	121	90
E-51-K		115	96	121	91	115	100	127	96	121	93
E-53-E	II, UU	121	94	124	87	121	95	124	90	118	88
E-53-H		118	94	123	87	123	104	Bkn in hdlg			
E-53-K		118	93	115	87	115	98	Bkn in hdlg			
E-56-H	II, WW	119	96	127	87	121	96	124	89	121	87
E-56-K		118	95	118	89	118	99	121	89	121	89
E-57-E	II, XX	118	93	129	87	126	96	126	89	126	89
E-57-H		126	93	132	87	129	93	138	85	138	88
E-57-K		121	93	133	72	130	77	130	86	133	93
E-60-E	Resin, ZZ	95	91	107	85	95	93	89	85	89	86
E-60-H		95	90	104	84	104	90	113	84	113	86
E-61-K	Special, AZ	88	87	100	78	91	89	88	82	80	77

(Continued)

Program 21

Table 3-CRE (Concluded)

Spec No.	Cement Type and Designation	1962 %E	1962 %V²	1964 %E	1964 %V²	1966 %E	1966 %V²	1968 %E	1968 %V²	1970 %E	1970 %V²
		1962-1970 Readings									
E-62-H	II, BY	116	94	124	86	118	95	118	88	113	86
E-62-K		Bkn in hdlg									
E-63-E	I, CX	118	91	118	87	115	96	123	87	120	83
E-63-H		113	93	118	87	115	95	120	86	117	85
E-63-K		116	93	119	86	119	94	Bkn in hdlg			

Pine Flat Dam Aggregate Program*

The purpose of this program was to determine the durability of lean mass concrete made with aggregates that were proposed for use in Pine Flat Dam, Kings River, California.

1947 Installation

In September 1947, six 8-cu-ft concrete cubes were installed at Treat Island. The aggregates used in the concrete were pit-run sand and gravel. The particles were predominantly hard, dense, igneous rock types. The characteristics of the six cubes were:

Cube No.	Type Cement	Cement Factor bags/cu yd	Air Content %	Slump in.†	Unit Theo Wt lb/cu ft
1	II	2.0	2.7-3.0	1-1/2 to 2	166.2
2	IV	2.0	2.7-3.0	1-1/2 to 2	166.2
3	II	3.0	2.7-3.0	1-1/2 to 2	166.0
4	IV	3.0	2.7-3.0	1-1/2 to 2	166.0
5	II	4.0	2.7-3.0	1-1/2 to 2	165.8
6	IV	4.0	2.7-3.0	1-1/2 to 2	165.8

† Wet-screened over 1-1/2-in. sieve.

Table 1-PF lists these specimens and gives their exposure record.

1949 Installation

In the fall of 1949, three concrete cores (10 in. in diameter by 18 in. long) were installed on the Treat Island exposure rack. These cores were taken from three 8-cu-ft cubes that were cast from air-entrained concrete containing type IV cement. The aggregates consisted of pit-run sand and gravel from the source from which aggregates were furnished for use in the project. The three cores had the following characteristics:

* See U. S. Army Engineer Waterways Experiment Station, CE, Investigation of Aggregates for Mass Concrete--Pine Flat Dam, Interim Report (Vicksburg, Miss., December 1948).

Core No.	Type Cement	Cement Factor bags/cu yd	Air Content,* %	Slump in.**
1A	IV	2.0	Approx 6.0	1-1/2 to 2
2A	IV	2.5	Approx 6.0	1-1/2 to 2
3A	IV	4.0	Approx 6.0	1-1/2 to 2

* Air content of that portion of the concrete containing aggregate smaller than 1-1/2 in. in size.
** Wet-screened over 1-1/2-in. sieve.

Table 2-PF lists these specimens and gives their exposure record.

Findings

The findings of the investigation were:

a. The cubes made from concrete with a 2-bag-per-cu-yd cement factor were the least durable and failed after approximately 15 winters. The $\%V^2$ never went above 100 (appreciably) and showed a steady decline after the first winter. The type IV cement specimen performed slightly better than the type II specimen.

b. The 3-bag-per-cu-yd cubes showed considerably more durability, but again, the $\%V^2$ did not get appreciably above 100 and showed a general decline. The specimens lasted approximately 23 winters with the type IV specimen showing up slightly better than the type II.

c. The specimens containing 4 bags per cu yd of cement were only slightly more durable, if any, than the 3-bag-per-cu-yd specimens. Although the initial velocities were generally about the same as the other specimens, the $\%V^2$ went well above 100 and remained much higher than the others until failure occurred. There was no appreciable difference in the type II and type IV cement specimens with regard to durability.

d. The performances of the 2.0-, 2.5-, and 4.0-bag-per-cu-yd cores were essentially the same for about 16 winters. Failure of the 2.0-bag-per-cu-yd core occurred after about 18 or 19 winters. The 2.5- and 4.0-bag-per-cu-yd cores failed after about 21 or 22 winters.

(Issued Jan 1973)

Table 1-PF

Program 22

Record of Observation and Testing of Cubes Made with Pine Flat Dam Aggregates,

1947 Installation, 1947- (Installed September 1947)

Beach Row 2

			1947; 1951-1959 Readings											
						672 Cycles 1953								
Cube No.	Cement Factor bags/ cu yd	Type Cement	0 Cycl 1947 Condition	486 Cycles 1951 Condition	587 Cycles 1952 Condition	Pulse Veloc fps	%V^2	783 Cycles 1954 %V^2	928 Cycles 1955 %V^2	1095 Cycles 1956 %V^2	1239 Cycles 1957 %V^2	1318 Cycles 1958 %V^2	1460 Cycles 1959 %V^2
1	2.0	II	Sound	Slight scaling and spalling	Scaling and heavy spalling	15,960	100	97	86	95	82	76	56
2	2.0	IV	Sound	Slight scaling	Scaling and spalling	15,750	100	107	97	91	98	92	88
3	3.0	II	Sound	Sound	Slight scaling and spalling	16,530	100	98	107	91	88	89	82
4	3.0	IV	Sound	Sound	Slight scaling and spalling	17,095	100	95	103	93	84	83	83
5	4.0	II	Sound	Slight scaling	Slight scaling and spalling	15,625	100	114	107	120	110	112	99
6	4.0	IV	Sound	Sound	Slight scaling and spalling	16,530	100	115	97	102	102	105	108

			1960-1971 Readings											
			1531 Cycles 1960 %V^2	1672 Cycles 1961 %V^2	1761 Cycles 1962 %V^2	1867 Cycles 1963 %V^2	2002 Cycles 1964 %V^2	2165 Cycles 1965 %V^2	2295 Cycles 1966 %V^2	2451 Cycles 1967 %V^2	2636 Cycles 1968 %V^2	2790 Cycles 1969 %V^2	2943 Cycles 1970 %V^2	3112 Cycles 1971 %V^2
1	2.0	II	53	Failed	(Completely disintegrated)									
2	2.0	IV	101	98	Failed									
3	3.0	II	90	92	91	95	75	89	*	75	61	*	Failed	
4	3.0	IV	88	88	91	88	85	82		81	88	73	72	Failed
5	4.0	II	109	112	111	105	95	93		108	103	80	72	Failed
6	4.0	IV	113	102	89	115	88	95		103	102	79	74	Failed

* Satisfactory pulse velocity readings were not obtained.

(Issued Jan 1973)

Table 2-PF

Program 22

Record of Testing of Cores Made with Pine Flat Dam Aggregates,

1949 Installation, 1949- (Installed October 1949)

Exposure Rack, Row 4 (W to E)

Core No.	Cement Factor bags/cu yd	1949-1959 Readings: 0 Cycles 1949 %E	161 Cycles 1950 %E	250 Cycles 1951 %E	351 Cycles 1952 %E	436 Cycles 1953 %E	436 Cycles 1953 Pulse Veloc fps	436 Cycles 1953 $\%V^2$	547 Cycles 1954 %E	547 Cycles 1954 $\%V^2$	692 Cycles 1955 %E	692 Cycles 1955 $\%V^2$	859 Cycles 1956 %E	859 Cycles 1956 $\%V^2$	1003 Cycles 1957 %E	1003 Cycles 1957 $\%V^2$	1074 Cycles 1958 %E	1074 Cycles 1958 $\%V^2$	1224 Cycles 1959 %E	1224 Cycles 1959 $\%V^2$
1A	2.0	100	102	110	123	128	15,790	100	128	100	149	107	148	90	145	100	150	100	142	92
2A	2.5	100	112	119	126	127	15,790	100	142	94	129	98	137	88	132	83	134	95	156	88
3A	4.0	100	123	129	131	127	15,955	100	129	98	138	109	146	104	144	94	144	100	158	90

Core No.	Cement Factor bags/cu yd	1960-1969 Readings: 1295 Cycles 1960 %E	1295 Cycles 1960 $\%V^2$	1436 Cycles 1961 %E	1436 Cycles 1961 $\%V^2$	1525 Cycles 1962 %E	1525 Cycles 1962 $\%V^2$	1631 Cycles 1963 %E	1631 Cycles 1963 $\%V^2$	1766 Cycles 1964 %E	1766 Cycles 1964 $\%V^2$	1929 Cycles 1965 %E	1929 Cycles 1965 $\%V^2$	2059 Cycles 1966 %E	2059 Cycles 1966 $\%V^2$	2215 Cycles 1967 %E	2215 Cycles 1967 $\%V^2$	2400 Cycles 1968 %E	2400 Cycles 1968 $\%V^2$	2554 Cycles 1969 %E	2554 Cycles 1969 $\%V^2$
1A	2.0	148	94	139	94	133	85	136	100	121	87	105	83	119	*	NR**	--	Failed	--		
2A	2.5	158	88	125	90	124	83	123	90	141	85	125	85	125	76	109	82	97	82	95	63
3A	4.0	157	104	148	104	142	107	129	109	116	96	103	85	95	74	85	67	70	74	†	††

Core No.	Cement Factor bags/cu yd	1970-1971 Readings: 2707 Cycles 1970 %E	2707 Cycles 1970 $\%V^2$	2876 Cycles 1971 %E	2876 Cycles 1971 $\%V^2$
2A	2.5	Failed	--		
3A	4.0	†	40	Failed	--

-- Dashed lines in "$\%V^2$" column indicate that a pulse velocity reading was not taken because of the deteriorated condition of the ends of the core.

* Satisfactory pulse velocity readings were not obtained in 1966 due to malfunction of testing equipment.

** No reading taken in 1967 due to bad condition of specimen.

† Unable to obtain satisfactory reading.

†† Pulse velocity reading was not taken.

Greenup Lock and Dam Specimens

In text:

Limestone aggregates: Blue Rock, Inc., Greenfield, Ohio

Portland cement: Type II, manufacturer unknown

Portland blast-furnace slag cement: Green Bag Cement Division, Pittsburgh Coke and Chemical Co., Pittsburgh, Pa.

Natural cement: Louisville Cement Co., Speed, Ind.

Air-entraining agent: Unknown

Greenup Lock and Dam Specimens

In October 1957, 14 concrete specimens were installed at Treat Island to develop information as to the durability of the aggregates used in the construction of Greenup Lock and Dam, Greenup, Kentucky.

The aggregates used were natural sand, natural gravel, and limestone. All specimens were made of air-entrained concrete with a water-cement ratio of 0.50 (by weight). The cementing medium was a blend of portland, natural, and portland blast-furnace slag cements in the following percentages:

	% by Wt Total Cementing Medium
Portland cement	38.4
Portland blast-furnace slag cement	38.4
Natural cement	23.2

Ten of the 14 specimens installed were concrete beams (6 by 6 by 30 in.); four were mass concrete cubes (2 by 2 by 2 ft).

Table 1-GLD gives mixture data and exposure record for these specimens.

Findings

a. The 2-ft cubes containing 3-in. maximum size coarse aggregate and 6.2 percent air were more durable than the cubes containing 6-in. maximum size coarse aggregate and 5.4 percent air.

b. Eight of the ten 6- × 6- × 30-in. beams had failed after six winters, regardless of size of aggregate or air content. There is no apparent reason for the fact that two of the beams containg 3/4-in. aggregate and 4.4 percent air lasted approximately two or three winters longer than the other beams.

(Issued Jan 1973)

Table 1-GLD

Program 23

Mixture Data and Record of Testing of Beams and Cubes Containing

Aggregates Used in Concrete of Greenup Lock and Dam, Ky.

1957- (Installed October 1957)

Specimen No.	Max Size Coarse Aggr in.	Slump in.	Entrained Air %	0 Cycles, 1957 %E Initial	0 Cycles, 1957 Pulse Veloc fps	0 Cycles, 1957 $\%V^2$	71 Cycles 1958 %E	71 Cycles 1958 $\%V^2$	221 Cycles 1959 %E	221 Cycles 1959 $\%V^2$	292 Cycles 1960 %E	292 Cycles 1960 $\%V^2$	433 Cycles 1961 %E	433 Cycles 1961 $\%V^2$	522 Cycles 1962 %E	522 Cycles 1962 $\%V^2$	628 Cycles 1963 %E	628 Cycles 1963 $\%V^2$	763 Cycles 1964 %E	763 Cycles 1964 $\%V^2$
							1957-1964 Readings													
2-ft Cubes on Beach Row 2, East to West																				
G-1	3	3	6.2	100	15,385	100	--	108	--	92	--	98	--	103	--	106	--	100	--	99
G-2	3	3	6.2	100	15,505	100	--	106	--	93	--	95	--	102	--	102	--	111	--	99
G-3	6	2-1/2	5.4	100	16,000	100	--	103	--	92	--	92	--	100	--	92	--	103	--	88
G-4	6	2-1/2	5.4	100	16,000	100	--	114	--	95	--	98	--	102	--	94	--	104	--	78
6- by 6- by 30-in. Beams on Exposure Rack, Row 2, West to East																				
G-5	1-1/2	3	6.2	100	14,045	100	117	115	122	101	121	106	99	92	72	--	Failed			
G-6	1-1/2	3	6.2	100	14,535	100	113	110	116	101	109	103	90	92	Failed					
G-7	1-1/2	3	6.2	100	14,450	100	116	110	120	100	118	101	95	83	64	--	Failed			
G-8	1-1/2	3	6.2	100	14,450	100	114	113	119	98	117	97	112	86	120	--	Failed			
G-9	1-1/2	3	6.2	100	14,450	100	116	109	118	102	118	101	95	84	127	--	Failed			
G-10	3/4	3	4.4	100	13,585	100	119	109	124	106	128	108	124	111	119	114	116	116	114	106
G-11	3/4	3	4.4	100	13,735	100	121	112	126	105	130	109	126	109	121	115	100	102	168	--
G-12	3/4	3	4.4	100	13,515	100	119	99	124	107	129	107	121	110	90	106	Failed			
G-13	3/4	3	4.4	100	13,515	100	120	98	126	107	126	107	124	106	76	73	Failed			
G-14	3/4	3	4.4	100	13,735	100	119	109	124	102	123	104	121	91	Failed					

Specimen No.	Max Size Coarse Aggr in.	Slump in.	Entrained Air %	926 Cycles 1965 %E	926 Cycles 1965 $\%V^2$	1056 Cycles 1966 %E	1056 Cycles 1966 $\%V^2$	1212 Cycles 1967 %E	1212 Cycles 1967 $\%V^2$	1397 Cycles 1968 %E	1397 Cycles 1968 $\%V^2$	1551 Cycles 1969 %E	1551 Cycles 1969 $\%V^2$	1704 Cycles 1970 %E	1704 Cycles 1970 $\%V^2$	1873 Cycles 1971 %E	1873 Cycles 1971 $\%V^2$
				1965-1971 Readings													
2-ft Cubes on Beach Row 2, East to West																	
G-1	3	3	6.2	--	*	--	95	--	98	--	97	--	89	--	NR	--	Failed
G-2	3	3	6.2	--	94	--	98	--	94	--	94	--	Failed				
G-3	6	2-1/2	5.4	--	92	--	**	--	Failed								
G-4	6	2-1/2	5.4	--	Failed												
6- by 6- by 30-in. Beams on Exposure Rack, Row 2, West to East																	
G-10	3/4	3	4.4	107	87	124	--	Failed									
G-11	3/4	3	4.4	Failed													

-- Dashed lines in "%E" column for 2-ft cubes indicate that fundamental transverse readings were not made on 2-ft-cube specimens. Dashed lines in "$\%V^2$" column for 6- by 6- by 30-in. beams indicate that the ends of the beam specimen were too rough to obtain satisfactory pulse velocity reading.

* Pulse velocity reading was not obtained on this cube in 1965; records do not indicate why this reading was omitted.

** Satisfactory pulse velocity reading was not obtained on this cube in 1966 because of the deteriorated condition of the faces of the cube at the soniscope reading stations.

NR No reading was taken on this cube due to oversight.

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

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Investigation of performance of concrete and concreting materials exposed to natural weathering. Vicksburg, 1960-62.
2 v. illus. 27 cm. (U. S. Waterways Experiment Station. Technical report 6-553)
Contents.-v.1. Active investigations.-v.2. Completed investigations.
___ _____Supplement. 1-
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nos. illus.

1. Concrete durability. 2. Weathering (concrete). (Series)
TA7.W34 no.6-553